U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-257 959

Groundwater Pollution in Europe - A Conference Summary

General Electric Co, Santa Barbara, Calif

Prepared for

Environmental Protection Agency, Washington, D C Office of Research and Monitoring

Jan 73

272037

PB 257 959

GROUNDWATER POLLUTION IN EUROPE — A CONFERENCE SUMMARY

GE73TMP-1

January 1973

GENERAL ELECTRIC COMPANY—TEMPO
CENTER FOR ADVANCED STUDIES
SANTA BARBARA, CALIFORNIA

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No. GE73TMP-01	2.	3. Recipient's Accession No. PB-257 959
4. Title and Subtitle: Groundwater Pollution in Europe - A Conference Summary			5. Report Date: Jan 73 6.
7. Author(s): David K. Todd			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: General Electric Co. Santa Barbara, California Center for Advanced Studies			10. Project/Task/Work Unit No. 11. Contract/Grant No. EPA-68-01-0759
12. Sponsoring Organization Name and Address: Environmental Protection Agency Washington, D.C. Office of Research and Monitoring			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstract

The 23 papers and 12 case histories presented at the conference and in this report covered all aspects of groundwater pollution with emphasis on European problems and practices. The conference made it clear that groundwater pollution is a problem in the heavily populated and industrial portions of Europe. Governmental bodies are aware of the situation and are working to formulate legislative and regulatory mechanisms to prevent and control pollution. In England new (1972) legislation will aid in stemming pollution from hazardous wastes; the pollution problems associated with high groundwater velocities and little filtration in the fissured chalk (limestone) aquifers are particularly troublesome.

17. Key Words and Document Analysis. 17a. Descriptors

*Water pollution,
*Ground water,
*Meetings,
*Europe,
Water pollution abatement,
Hydrogeology,
Aquifers,
Monitoring,
Water quality,
Ground water recharge,
Drainage,
Water wells,
Fertilizers,
Agriculture,
Fluid infiltration,
Silos,
Inorganic nitrates,
Petroleum products,
Pesticides,
Radioactive isotopes,
Salt water intrusion.

17b. Identifiers/Open-Ended Terms

17c. COSATI Field Group 13 B 8 H

18. Availability Statement: National Technical Information Service Springfield, Virginia 22161	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 89p
	20. Security Class (This Page) UNCLASSIFIED	22. Price 5.00/3.00

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

Copy No. 5

GROUNDWATER POLLUTION IN EUROPE — A CONFERENCE SUMMARY

David K. Todd
Consultant

Prepared for
Office of Research and Monitoring
Environmental Protection Agency

GE73TMP-01

January 1973

TEMPO
GENERAL ELECTRIC COMPANY
CENTER FOR ADVANCED STUDIES
SANTA BARBARA, CALIFORNIA

The work upon which this publication is based was supported by the Environmental Protection Agency under Contract No. 68-01-0759.

CONTENTS

ILLUSTRATIONS	vi
ABSTRACT	vii
SECTION 1—INTRODUCTION	1
THE CONFERENCE	1
THE WATER RESEARCH ASSOCIATION	2
PURPOSE OF THIS REPORT	2
SECTION 2—SUMMARIES OF PAPERS	4
GROUNDWATER POLLUTION CONTROL	4
HYDROGEOLOGICAL FACTORS IN GROUNDWATER POLLUTION	6
RESEARCH AT WPRL RELATED TO GROUNDWATER POLLUTION PROBLEMS	8
SAFEGUARDING THE WATER SUPPLIES IN UPPSALA, SWEDEN	10
MICROBIOLOGICAL ASPECTS OF GROUNDWATER POLLUTION	11
SOME CHEMICAL PRINCIPLES OF GROUNDWATER POLLUTION	14
MONITORING RIVER WATER TO CONTROL PURITY OF DUNE RECHARGE WATER	15
THE ROUTINE DISCHARGE OF EFFLUENTS TO THE UNDERGROUND — PRACTICE AND CONTROL	18
DEFINING THE SPREAD OF GROUNDWATER CONTAMINATION BELOW A WASTE TIP	19
INFILTRATION FROM FARM SILAGE	22
NITRATE POLLUTION OF CHALK GROUNDWATER IN EAST YORKSHIRE: A HYDROGEOLOGICAL APPRAISAL	23

AGRICULTURAL FERTILIZERS, SLURRY DISPOSAL, AND NITRATE POLLUTION OF GROUNDWATERS 24

POLLUTION AFFECTING WELLS IN THE BUNDER SANDSTONE 25

PROTECTION OF AQUIFERS AGAINST PETROLEUM POLLUTION IN SWITZERLAND 27

A RECENT CASE HISTORY OF GROUNDWATER POLLUTION BY ORGANIC SOLVENTS 29

THE IMPACT OF ORGANIC PESTICIDES AND HERBICIDES UPON GROUNDWATER POLLUTION 30

COMPUTER SIMULATION OF POLLUTION FRONT MOVEMENT 32

FLOW TRACING USING ISOTOPES 34

LOCAL STUDIES OF MISCIBLE POLLUTIONS OF GROUNDWATER: THE SINGLE WELL PULSE TECHNIQUE 36

DEEP WELL INJECTION OF LIQUID WASTE 37

WELL SCREENS — SOME NOTES ON MATERIALS 40

UNCLOGGING OF BOREHOLES 41

SECTION 3—SUMMARIES OF CASE HISTORIES 42

POLLUTION PREVENTION AT TWO REFUSE TIPS 42

DREDGE MINING FOR RUTILE — EFFECTS ON WATER QUALITY 42

CASE HISTORIES OF SOME PHENOLIC POLLUTIONS IN ESSEX 43

PETROLEUM POLLUTION AT GREAT HOSPITAL, NORWICH 43

STUDIES FOR THE PREVENTION OF OIL POLLUTION NEAR BRATISLAVA, CZECHOSLOVAKIA 44

POLLUTION OF THE FLOOD PLAIN GRAVELS BY GAS WORKS WASTE 44

POLLUTION OF A SPRING SOURCE BY SILAGE LIQUOR 45

SALINE UNDERSEEPAGE PROBLEMS AT CHOWILLA DAM 45

SALINE POLLUTION OF UNDERGROUND SUPPLY AT LEICESTER LANE BOREHOLE 46

THREE CASE HISTORIES OF GROUNDWATER POLLUTION IN BRIGHTON CHALK 46

CASE HISTORIES OF GROUNDWATER POLLUTION IN THE ESSEX WATER COMPANY'S AREA 47

LEGAL AND TECHNICAL ASPECTS OF GROUNDWATER POLLUTION CONTROL 48

SECTION 4—NOTES ON THE DISCUSSIONS 49

SECTION 5—INFORMATION FROM EUROPEAN COUNTRIES 54

DENMARK 54

SWITZERLAND 54

THE NETHERLANDS 55

Letter by Drs. H. G. van Waegeningh 55

WEST GERMANY 60

Regulations for Protective Areas for Drinking Water Part I – Protective Areas for Groundwater 60

SECTION 6—NOTES ON REFERENCE MATERIALS 78

ILLUSTRATIONS

Figure	Title	Page
1	Cross section of a waste disposal pit showing seepage through an unsaturated zone occupied by clay lenses.	7
2	Swedish two-pump method for removal of oil pollution from a well.	12
3	Geohydrologic cross section of The Netherlands.	16
4	Distribution of chloride downstream from a landfill in West Germany.	21
5	Experimental results from Switzerland on the distribution of oil in soil as a function of time.	28
6	Computer results from France showing movement of pollution from a river through an aquifer to a well field.	33
7	Design of a waste disposal well with fluid and mechanical seals.	39

ABSTRACT

On September 25-27, 1972, the Water Research Association, a quasi-governmental research organization in England, organized a Groundwater Pollution Conference. The conference was held at the University of Reading, Reading, England, and was attended by some 200 participants. Most of the participants came from England and the remainder from various European countries. The author was the only participant from the United States.

The 23 papers and 12 case histories presented at the conference covered all aspects of groundwater pollution with emphasis on European problems and practices. The papers and case histories were published and distributed to participants in advance of the conference; therefore, most of each session's time was devoted to discussion.

Because of the limited American participation in the conference and the general unavailability of the conference publications, this report has been prepared to summarize information on European groundwater pollution generated by the conference. Highlights of the papers and case histories are presented in summary form followed by notes on discussions at the conference, by supplemental information from selected European countries obtained during and subsequent to the conference, and finally by a few notes on reference materials.

The conference made it clear that groundwater pollution is a problem in the heavily populated and industrial portions of Europe. Governmental bodies are aware of the situation and are working to formulate legislative and regulatory mechanisms to prevent and control pollution. In England new (1972) legislation will aid in stemming pollution from hazardous wastes; the pollution problems associated with high groundw velocities and little filtration in the fissured chalk (limestone) aquifers are particularly troublesome.

In Sweden and Switzerland considerable attention is being given to minimizing groundwater pollution caused by oil and petroleum products. In West Germany the use of protective zones which govern land use around groundwater supply installations appears to be an effective pollution preventative.

SECTION I

INTRODUCTION

The Conference

On September 25-27, 1972, a Groundwater Pollution Conference was held at the University of Reading, Reading, England, under the sponsorship of the Water Research Association. Attendance totaled approximately 200 persons, of whom 30 were from outside of England. The author was the only participant from the United States.

A total of 23 papers were presented during the three days of the conference. Fifteen papers were from England, two papers came from France, and one each originated from Ireland, Sweden, Netherlands, West Germany, Switzerland, and the United States (however, this paper was prepared while its author resided in England). Thus, the conference was oriented to the occurrence, effects, and control of groundwater pollution in Europe.

Before the conference each participant was mailed 400 pages of material bound into two volumes. These contained preprints of the 23 papers to be presented as well as 12 detailed case histories of groundwater pollution. With this material in hand, it was assumed that participants would have read the two volumes in advance of the conference. As a consequence, the conference was designated as a "working conference." Papers were presented in brief five-minute summary form only, thereby enabling the bulk of each session's time to be devoted to discussion. This technique proved successful in that it stimulated discussions, expressions of opinions, and verbal reports of experiences involving groundwater pollution. In none of the nine sessions was there a shortage of discussion so that in every instance the chairman had to terminate the exchanges to close the session. The case histories were for information only and were not specifically discussed at the conference.

All of the discussions were tape recorded. From this record the key discussion points will be summarized and published by the

Water Research Association as a third volume of the conference publications. A bibliography will also be included in that report.

The author took part in several of the discussions. At one point the active role that the Environmental Protection Agency is taking in planning to monitor groundwater quality and to control subsurface pollution in the United States was described. At the request of the chairman of the closing session, the author spoke on behalf of all of the foreign participants at the conference, commenting upon the value of the conference and expressing appreciation to the Water Research Association for its leadership in organizing the conference.

The Water Research Association

The conference was organized by the Water Research Association, a quasi-governmental organization located in the village of Medmenham, about 15 miles east of Reading, England. The Association is the largest water resources research organization in England. Its funds come primarily from water supply, sewerage, and river authorities all over England and secondarily from the English government. The authorities, as members of the Association, receive results of new research on all aspects of water resources and can request technical assistance on particular local water problems. Contract research is also undertaken for government agencies, private companies, and even foreign governments.

The diversity of work covered by the Association is large. Thus, research topics include, among others, analog and digital modeling of water distribution systems and of groundwater basins, studies of artificial groundwater recharge, analysis of failures of plastic pipe, and development of sensitive current meters to measure water velocities in wells.

Purpose of This Report

This report is a summary of the conference together with related information on groundwater pollution in Europe gained by the author during the course of his attendance at the conference. Because the United States was represented by only one person at the conference and because the three conference publications are lengthy and not available for general distribution, it was felt that a summary report

SECTION I

INTRODUCTION

The Conference

On September 25-27, 1972, a Groundwater Pollution Conference was held at the University of Reading, Reading, England, under the sponsorship of the Water Research Association. Attendance totaled approximately 200 persons, of whom 30 were from outside of England. The author was the only participant from the United States.

A total of 23 papers were presented during the three days of the conference. Fifteen papers were from England, two papers came from France, and one each originated from Ireland, Sweden, Netherlands, West Germany, Switzerland, and the United States (however, this paper was prepared while its author resided in England). Thus, the conference was oriented to the occurrence, effects, and control of groundwater pollution in Europe.

Before the conference each participant was mailed 400 pages of material bound into two volumes. These contained preprints of the 23 papers to be presented as well as 12 detailed case histories of groundwater pollution. With this material in hand, it was assumed that participants would have read the two volumes in advance of the conference. As a consequence, the conference was designated as a "working conference." Papers were presented in brief five-minute summary form only, thereby enabling the bulk of each session's time to be devoted to discussion. This technique proved successful in that it stimulated discussions, expressions of opinions, and verbal reports of experiences involving groundwater pollution. In none of the nine sessions was there a shortage of discussion so that in every instance the chairman had to terminate the exchanges to close the session. The case histories were for information only and were not specifically discussed at the conference.

All of the discussions were tape recorded. From this record the key discussion points will be summarized and published by the

Water Research Association as a third volume of the conference publications. A bibliography will also be included in that report.

The author took part in several of the discussions. At one point the active role that the Environmental Protection Agency is taking in planning to monitor groundwater quality and to control subsurface pollution in the United States was described. At the request of the chairman of the closing session, the author spoke on behalf of all of the foreign participants at the conference, commenting upon the value of the conference and expressing appreciation to the Water Research Association for its leadership in organizing the conference.

The Water Research Association

The conference was organized by the Water Research Association, a quasi-governmental organization located in the village of Medmenham, about 15 miles east of Reading, England. The Association is the largest water resources research organization in England. Its funds come primarily from water supply, sewerage, and river authorities all over England and secondarily from the English government. The authorities, as members of the Association, receive results of new research on all aspects of water resources and can request technical assistance on particular local water problems. Contract research is also undertaken for government agencies, private companies, and even foreign governments.

The diversity of work covered by the Association is large. Thus, research topics include, among others, analog and digital modeling of water distribution systems and of groundwater basins, studies of artificial groundwater recharge, analysis of failures of plastic pipe, and development of sensitive current meters to measure water velocities in wells.

Purpose of This Report

This report is a summary of the conference together with related information on groundwater pollution in Europe gained by the author during the course of his attendance at the conference. Because the United States was represented by only one person at the conference and because the three conference publications are lengthy and not available for general distribution, it was felt that a summary report

would be a useful and effective means to make the conference information more generally available in the United States.

The summaries of the papers and case histories that follow are intended to present the highlights presented by the authors. No interpretations of the contributions have been attempted. For detailed supporting material such as chemical and mathematical expressions or tables of data, reference to the original papers will be required.

In retrospect it seems clear that most European nations today are aware of the importance of groundwater pollution and the need for appropriate governmental action. Some of the nations lead the United States in formulating governmental regulations to prevent and to control groundwater pollution. Further attention to European activities appears to be warranted.

SECTION 2

SUMMARIES OF PAPERS

Groundwater Pollution Control

by D. Mercer, Directorate General Water Engineering, Department of the Environment.

Approximately one-third of the public water supplies of the United Kingdom is obtained from underground sources, and the need to protect the purity of this important source is obvious. Pollution of groundwater is not normally easily noticed, and the detection of a source of pollution may present difficulty, particularly where the nature of the underground strata permits polluting material to travel considerable distances. Pollution of surface waters, however, is easier to detect.

One of the most important differences from the pollution aspect is the great advantage conferred on groundwater generally by the purifying effect of passage of water through soil and porous strata. The possibilities for pollution of groundwater are numerous: causes can include deposits on the land surface and discharges made directly to underground strata.

The control of groundwater pollution is by common law, by statute law, by bylaws, and also by notification and consultation arrangements and similar semi-judicial procedures. Under Common Law a landowner has a right of action against anyone who pollutes water percolating through his land so that it reaches the owner's land in a polluted condition.

The Water Act of 1945 in one section states:

> "If any person is guilty of an act or neglect whereby any spring, well or adit, the water from which it is used or likely to be used for human consumption or domestic

> purposes . . . , is polluted or likely to be polluted, he shall be guilty of an offence against this act:
> Provided that nothing in this section shall be construed as prohibiting or restricting —
> (a) any method of cultivation of land . . . ; or
> (b) the reasonable use of oil or tar on any highway . . . ."

This section does not permit action to be taken to prevent the pollution of groundwater before it occurs but only after the source of and the responsibility for the pollution has been established.

Another section of the same Act permits water supply utilities to make bylaws which define areas for protecting water against pollution; however, the bylaws are rarely used, possibly because compensation must be paid to owners for curtailment of legal rights.

The Water Resources Act of 1963 specifies that no waste may be discharged into underground strata through a well without the consent of the local river authority. The authority may refuse consent, or grant it unconditionally or subject to conditions specifying the nature, composition, and volume of the effluent; the strata into which it may be discharged; and the measures taken to protect water in other underground strata. The provision and use of observation wells with facilities for inspection may be required.

The recently passed Deposit of Poisonous Waste Act of 1972 is directed toward protecting groundwater supplies from pollution in that it makes it an offense to deposit on land waste of a poisonous, noxious, or polluting nature which could give rise to an environmental hazard. The threat of pollution is sufficient to enable the Act to be applied; it is not necessary to show that actual pollution has occurred.

The construction of lagoons for refuse disposal are controlled by planning authorities, who in turn consult other authorities on applications for developments which would cause inland water pollution. The construction and siting of septic tanks is governed by building regulations " . . . so as not to render liable to pollution any spring, stream, well . . . used or likely to be used for drinking, domestic, etc., purposes."

Hydrogeological Factors in Groundwater Pollution

by A. Hunter Blair, The Water Research Association

Groundwater pollution can originate from a point source within the recharge area of an aquifer. The risk of pollution is highest in urban areas, where large volumes of wastes are concentrated into relatively small areas, and is further increased where these areas contain permeable surface deposits, crevices, or fissures. By contrast, slow deterioration of groundwater quality may occur over broad regional areas. Thus, groundwater pollution falls into two categories: (a) individual, short-term, and local pollution, and (b) slow decline in quality over large areas requiring long-term and extensive investigations.

Contaminating sources at or essentially at the ground surface include individual sewage disposal systems, refuse disposal sites, settling basins for disposal of sewage and liquid waste products, sewage and industrial wastes discharged into streams supplying groundwater, agricultural sources, artificial groundwater recharge, urban runoff, spillage of polluting materials, leakage from tanks and pipelines, storage of unprotected chemical products, and acid mine drainage water. Subsurface contaminating sources consist of subsurface transportation and/or storage, waste injection wells, interaquifer movements, aquifer use, well construction and development methods, and artificial groundwater recharge through wells.

Many factors determine the safe distance between a groundwater supply and a source of pollution. These include local geology, topography, nature of topsoil and underlying strata, thickness of water-bearing strata, depth to water table, slope of water table, seasonal fluctuations of water table, direction and rate of movement of groundwater, extent of surface drainage area, and well construction. In general, the distance should be the maximum that economics, land ownership, geology, and topography will allow. The most important measure taken for prevention of pollution is the establishment of protection zones within which activities capable of polluting groundwater are prohibited or restricted.

The hydrogeology of an area exercises a dominant control over what happens to a pollutant introduced underground (see, for example, Figure 1). Generally a polluted water moves downward through a

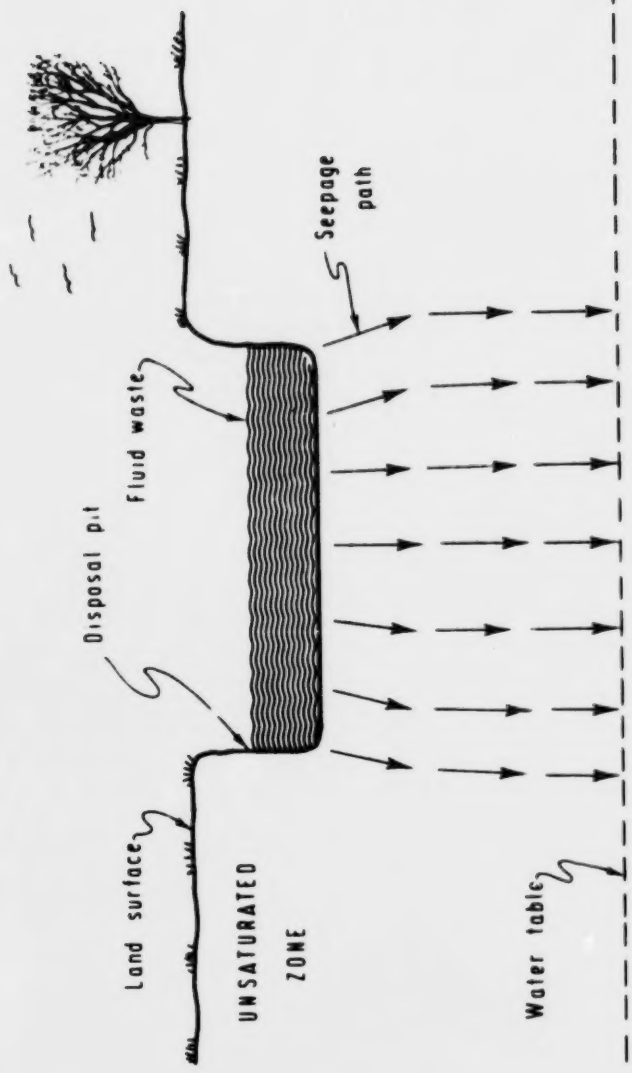

Figure 1. Cross-section of a waste disposal pit showing seepage through an unsaturated zone occupied by clay lenses.

zone of aeration to a saturated zone and then laterally to points of discharge. Access of pollution to an aquifer can occur by percolation through a zone of aeration, by infiltration and migration in the zone of saturation, by vertical leakage, or by direct injection. Geologic structure of the rock materials, geologic movements such as tilting, joints, and faults, and topography are all important influences. Shallow unconfined aquifers are most susceptible to pollution because they may be either in direct contact with surface sources of pollution or because there is little or no natural treatment afforded by the overlying strata.

A substance in solution and flowing through an aquifer mixes by molecular diffusion and mechanical dispersion. From hydraulic considerations the path of a pollutant underground can be evaluated if information about the aquifer is available; consequently, all types of hydrogeologic information should be analyzed. Problems of groundwater pollution require the joint services of engineers, hydrogeologists, chemists, and biologists.

Research at WPRL Related to Groundwater Pollution Problems

by Dr. H. A. C. Montgomery and A. B. Wheatland, Water Pollution Research Laboratory.

The Water Pollution Research Laboratory (WPRL) has conducted during the last thirty years several investigations of groundwater pollution. These are briefly reviewed.

Experiments were conducted on the feasibility of recharging sandstone aquifers with sewage effluent. Continuous application resulted in a percolate with appreciable ammonia, but intermittent application resulted in almost complete removal. The removal mechanism consisted of cation exchange followed by nitrification; added nitrogen was leached as nitrate and a fall in pH usually occurred. Most of the BOD was satisfied during percolation but residual organic matter was indicated. Ammonia removal was found to be affected by soil and water temperatures. Percolation resulted in removal of all manganese, most zinc and nickel, and some iron, chromium, lead, and copper. The removal of bacteria ranged from 81 to 96.5%.

Respirometric tests were run on liquids draining through landfills. Results showed that domestic refuse can give rise to liquors in which the organic matter is either easily or incompletely degradable by aerobic biological action, and also confirmed that such liquors do not prevent nitrification. Calculations were made of the pollution of well waters which might occur if all the percolate from a landfill reached a point of abstraction, including increases in nitrogen, chloride, sulphate, BOD, iron, and manganese.

Study was made of pollution of a spring resulting from discharge of "pot-ale," the residue from the distillation of whiskey, into a pit 300 meters away. An odor of hydrogen sulfide and growth of filamentous bacteria were noted. Alternative disposal methods were recommended.

Two studies of the composition of septic tank liquors were conducted. One investigation showed that good final effluents, as judged by BOD and ammonia, were produced by biological filtration of the septic-tank effluents as long as the loading did not exceed that of conventional sewage-treatment practice. The flow of septic tank liquor, which would normally enter the ground, was found to be about 100 to 150 liters per person served per day. The second study concerned the effect of synthetic detergent materials on septic tank performance. Results suggested a partial inhibition of anaerobic digestion by the surfactant.

Detailed studies of the biodegradation of cyanide led to conclusions that concentrations of cyanide up to 10 mg/l would probably be removed from a solution percolating into the ground from a landfill unless (a) ground temperature were below 10°C, (b) certain pH ranges were exceeded, (c) the solution became anaerobic, (d) ferro- or ferricyanide were formed, or (e) organisms which can utilize cyanide were absent.

A new research project will study the potential pollution hazards to surface and groundwaters resulting from deposition of solid and concentrated liquid waste materials in landfills. Emphasis will be on the more toxic substances, but municipal refuse will also be included. Chemical and hydrogeological studies will be made at selected sites, supplemented by laboratory investigations of the fate of hazardous substances in aquifers. It is hoped that the studies will yield background information which will help in the development of a safe, economical, and logical policy toward waste disposal.

Safeguarding the Water Supplies in Uppsala, Sweden

by Dr. J. Sidenvall, Department of Public Works
and University Institute of Geology, Uppsala

The geology and recurrence of groundwater in the vicinity of Uppsala, Sweden, are described. Water supplies have been obtained from springs and wells in the past; however, with heavy overdraft on the groundwater resulting from an increase in the population, an artificial recharge system was implemented. River water is passed through rapid sand filters and is then recharged into basins overlying the Uppsala esker. The water percolates 20 meters through the esker before reaching the water table. Tracer tests using uranin have been conducted to ascertain the movement of the recharged water.

Water samples collected from near the recharge basins showed high sulfate concentrations during spring and autumn but normal values during summer and winter. Investigation of the curious phenomenon revealed that agricultural fields in the vicinity were fertilized every spring and autumn with superphosphate, containing 40 percent sulfate. Surface water from this area was dammed by a ditch which discharges into a gravel pit, thus permitting infiltration into the esker.

In the last 20 years oil has become the common fuel in Sweden for heat. As a result there are now several hundred thousand underground tanks, all capable of polluting the groundwater. Risks of pollution are derived from overflow of tanks, bursting tanks, and corrosion of tanks and pipelines.

Oil percolating through sand or gravel sinks in a "pear" like form until it reaches the capillary zone. There it spreads out on the water table and moves with the groundwater. Variable stratified layers can modify the oil distribution. When oil spill accidents occur, the first step is to try to stop the leakage. Knowing the amount of oil spilled permits estimates to be made of how far it has penetrated into the ground and of how much oil will be permanently attached to grains of the aquifer. Soil saturated with oil is removed; where the soil has less than 2 to 3 percent oil, it is left because generally this threshold percentage means the oil is permanently fixed to the soil matrix. Where large quantities of oil have reached

the water table, a ditch or well is constructed. Water is pumped to create drainage toward the ditch or well, while a second small pump removes an oil-water mixture from the water surface (see Figure 2).

Oil leakage in clays is common because of the galvanic action which promotes corrosion of buried tanks and pipelines. To minimize the effect, a 0.5 meter layer of sand should be placed around tanks. Where tanks are placed in contact with the water table, holes developing in tanks usually occur at the water table, again indicating galvanic action. Oil leakage in clays is difficult to control; dry clays spread oil faster than do wet clays. Excavation of oil-polluted clays is usually undertaken; care must be taken not to dig too rapidly as oil can drain into the pit and unnecessarily pollute more soil.

Oil-polluted soil is disposed of by spreading it in a layer less than 0.2 meter deep on top of refuse in a landfill. The high temperature of bacterial action in the refuse plus aeration causes the oil molecules to decompose in less than six months. Any loose oil in the soil is absorbed by the underlying refuse.

Special alarm lists have been developed to handle emergencies created by spills of oil and chemicals. A study is underway to define how, where, and when potentially hazardous substances are transported.

Microbiological Aspects of Groundwater Pollution

by Dr. M. Hutchinson, The Water Research Association.

The role of micro-organisms in groundwater pollution may be beneficial or detrimental depending on the types of organisms involved and the specific circumstances in which they are present. The beneficial activities include (a) processes of purification in which pollutants, including biological agents, are degraded to innocuous products or pathogenic organisms are reduced in numbers, (b) the cycling of certain essential elements in nature including carbon, nitrogen, phosphorous and sulfur, and (c) degradation of man-made pollutants such as pesticides, herbicides, detergents, and other

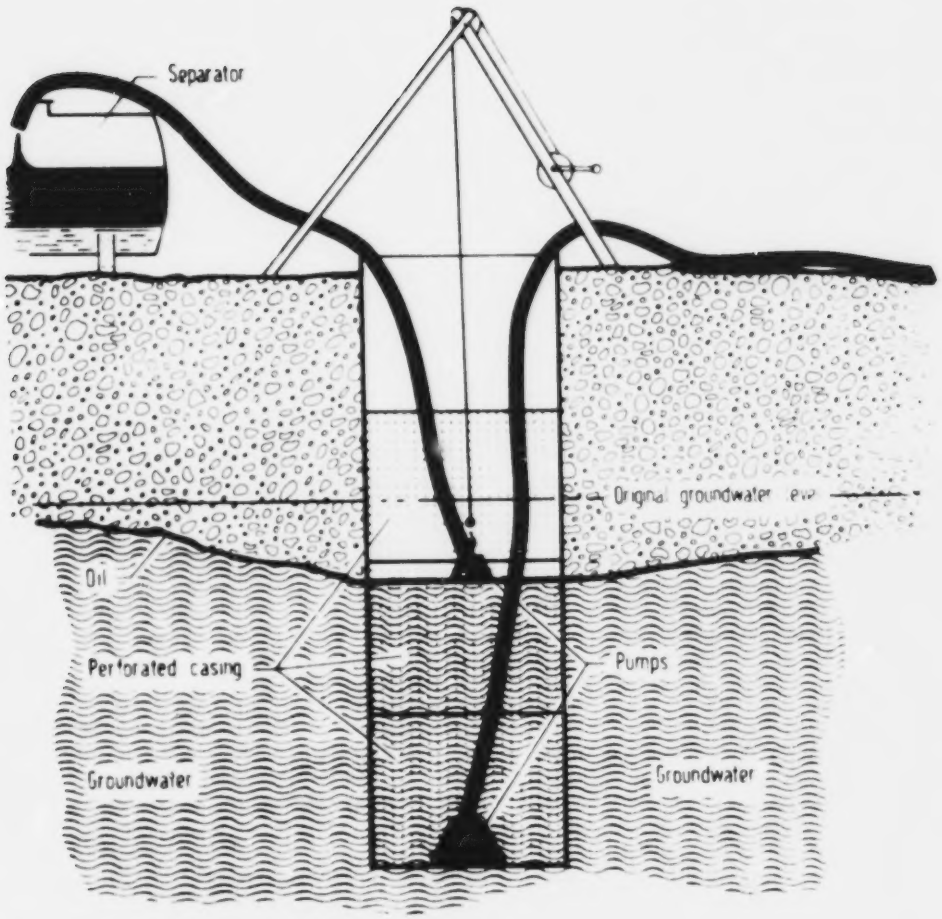

Figure 2. Swedish two-pump method for removal of oil pollution from a well.

unnatural chemical compounds. The same processes, however, may produce secondary aspects of pollution: depletion of the dissolved oxygen in the water leading to biological nitrate reduction to ammonia, reduction of sulfate to sulfide with precipitation as ferrous sulfide, and mobilization of iron from the soil by reduced oxygen tension leading to deposition elsewhere through activities of iron bacteria.

A major concern in potable groundwater supplies is the health hazard from its recent contamination by sewage and human excrement. The diseases transmitted by water primarily originate in the alimentary tract. Pathogenic organisms pass into the environment in the faeces or urine of man from either a diseased person or a carrier, including livestock, wild animals, and birds. Agents of enteric diseases of man transmitted by water include cholera, salmonella, Shigella, enteropathogenic Escherichia coli, viral pathogens (infectious hepatitis, Polio, Coxackie, and ECHO viruses), and animal parasites.

For water-borne disease to occur the causative agent must contaminate the water supply, survive, and be consumed by another individual. The chances of this person becoming infected depend on the susceptibility of the individual, the virulence of the infective agent, the number of pathogens in the environment, and the survival of the pathogens.

Control of the spread of pathogens has been primarily by isolation and treatment of sewage and protection of water supplies from sewage pollution. For groundwater supplies protection is based on careful siting of extractions in relation to pollution sources, sound construction of wells, and correct operation of wells. Water treatment of pumped groundwater may be needed, and disinfection should be practiced as a final defense. Natural mechanisms for removal of pollutants in groundwater are filtration; adsorption; biodegradation; death due to excessive competition for nutrients and oxygen, antagonism, predation, or simply detention; and dilution by dispersion.

Vertical movement of water in the unsaturated zone, which is essentially aerobic, is of great importance because the major part of purification occurs through biological agencies. Once pollution reaches the water table it is carried passively with comparatively little opportunity for further change. Numerous studies have been made of the distance of travel of pollution under various hydrogeological conditions. Despite many anomalies in the observed data, general

principles are evident, and these can be interpreted in terms of guidelines or recommended safety zones between wells and potential sources of pollution. Precise safe distances cannot be specified, however, because of the variables such as geology, chemistry of pollutants, hydrology, biology, climate, and topography.

Some Chemical Principles of Groundwater Pollution

by E. S. Hall, The Water Research Association.

Chemical equilibrium in groundwater can generally be assumed because groundwater usually remains for long periods in contact with the rock which governs its composition and because most non-equilibrium oxidation-reduction systems in nature are used by micro-organisms for respiration through enzyme catalysts. An artificial influence on the chemical equilibrium systems is the introduction of air into the ground by groundwater abstraction, agriculture, and mining. This distorts the natural oxidation balance in the ground and leads to pollution by aeration.

Nitrogen has four naturally occurring oxidation states; in increasing order of oxidation these are ammonium, nitrogen gas, nitrite, and nitrate. The ultimately stable form of nitrogen is nitrate, which is formed microbially at temperatures greater than 10°C. Nitrate is not produced naturally except when nitrogen fixation occurs in the presence of organic substances. Nitrate enters the groundwater by the flushing of air spaces by rainwater after having been produced by the bacterial oxidation of ammonia and cell protein. Within the United Kingdom there is evidence of a relationship between nitrate in groundwater and organic content of soil. Deterioration of soil quality has been caused by cereal production, involving application of inorganic ammonia fertilizer. The soil, aerated by plowing, favors the oxidation of ammonia to nitrate, leading to the inevitable loss of soil humus.

Another example is the oxidation of iron sulfide. Iron contamination of groundwater was originally caused during the formation of an aquifer by the deposition of organic substance which subsequently was probably reduced by bacteria to form iron sulfide. But given the

iron sulfide content of an aquifer, the factor which governs the amount of dissolved iron in groundwater is the quantity of dissolved oxygen which periodically reaches the sulfide. Sulfide will normally be more concentrated at the lower levels of an aquifer so that iron dissolution increases with aquifer exploitation. Iron in groundwater is preferable to the permanent precipitation of iron oxide in the aquifer with unremitting pumping. Introduction of soluble organic material into an aquifer should be avoided as the aquifer composition would be worsened.

Permanent removal of organic substances from groundwater can occur by four processes: (a) filtration of insoluble matter, (b) consumption of substances for microbial respiration, (c) precipitation of humus by microbial fermentation, and (d) consumption of substances for microbial cell synthesis.

As for inorganic pollutants in groundwater, the chemical equilibria prevailing are largely governed by pH and bicarbonate concentration. Groundwater acquires carbon dioxide from microbial respiration and fermentation in soil and calcium carbonate is subsequently dissolved to form bicarbonate. The solubility of other ions, such as phosphate, fluoride, chloride, sulfate, iron, and heavy metals, are affected similarly.

Adsorpiton and precipitation of pollutants on grains of a aquifer raise the question as to whether the deposits can impede the flow of water. With a stationary front of an organic pollutant, a steady state has occurred due to oxidation of the substance by microbial action. For this to occur without the microbial growths causing blocking is probably an indication that the pollutant is present in very low concentrations in the groundwater.

Monitoring River Water to Control Purity of Dune Recharge Water

by Dr.G. Drost, Duinwaterleidung van Den Haag,
The Netherlands.

The large waterworks of the western half of the Netherlands are practically all situated in the dunes, the only freshwater source (see Figure 3), and are running short of freshwater. Because of this, the

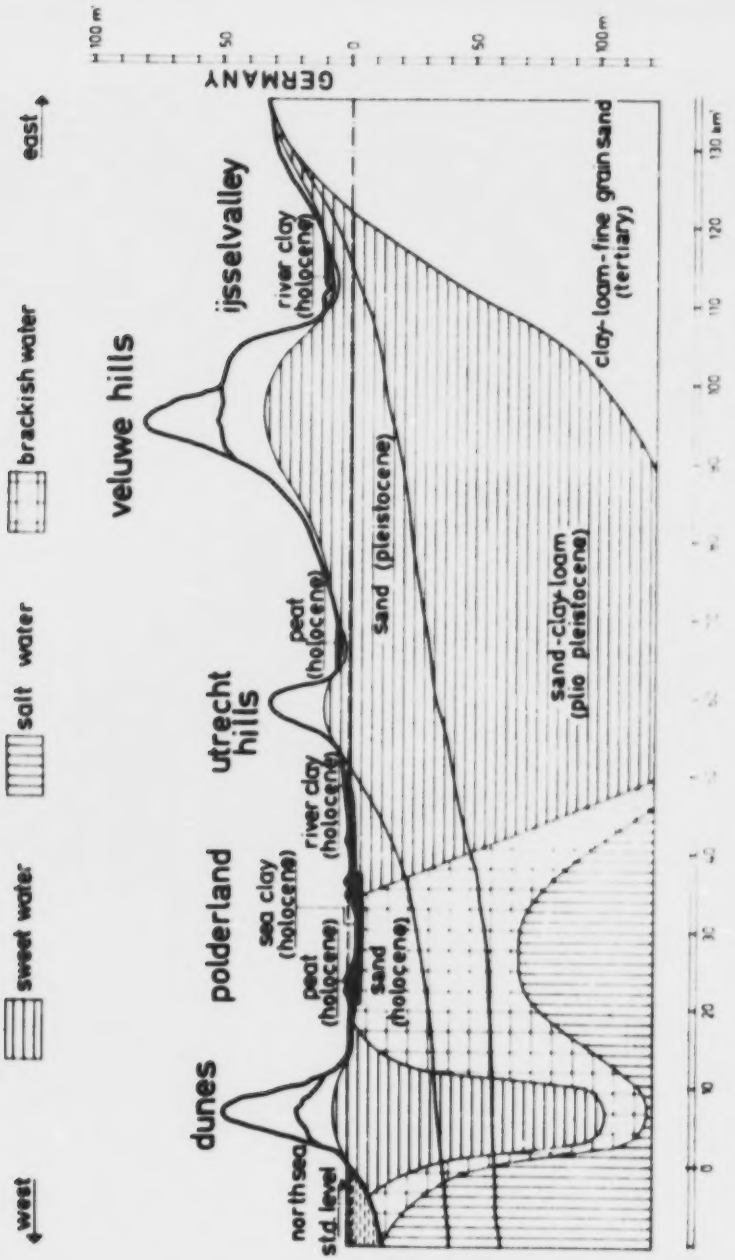

Figure 3. Geohydrologic cross-section of The Netherlands.

dunes are now recharged by infiltration of prefiltered Rhine River water. The water is recharged into ponds and pumped from the ground by canals, drains, or wells located about 70 meters away. The water remains in the ground for one to two months or more, and during its passage through the ground there is a considerable change of composition.

The original dune water came from rainfall. Micro-organisms consumed the oxygen, making the water anaerobic. Iron and manganese were in solution, hardness was dissolved from shell fragments, ammonia was liberated by microbiological action from peat, and sulfate reduction caused hydrogen disulfide and methane to be present.

Rhine River water is badly polluted but is used for recharge because it is the only large source of water available. The quality composition of the water decreases from year to year, and yearly fluctuations also occur due to wet and dry years. The most important pollution indicators are chloride, permanganate number, total organic carbon, color, taste number, phenol, ammonia, nitrite, nitrate, phosphate, oxygen saturation, BOD, detergents, fluoride, and coli-count. Recently, there is increasing evidence of specified organic pollutants in relatively high concentrations.

The river water is first passed through rapid sand filters to remove sediment and is then chlorinated to prevent biological scaling of the transport pipe. In the infiltration ponds algae and water plants grow, while changes in pH, phosphate, ammonia, nitrate, and silicate occur.

Changes in water quality during the flow from ponds to wells have been monitored by rows of observation wells along streamlines. Reductions are noted in organic content, color, taste, and ammonia; however, the presence or absence of peat layers in the sand produces different results. In recent years the effective reduction in taste number has diminished, causing considerable concern.

The Routine Discharge of Effluents to the Underground — Practice and Control

by N. J. Nicolson, Thames Conservancy.

Prior to the introduction of sewer systems into rural areas, most domestic properties were drained to septic tanks. Because the quality of effluents from such tanks did not meet standards of discharge into surface streams in the Thames Conservancy area, disposal was by underground drainage systems.

The Water Resources Act of 1963 required existing dischargers to underground strata to obtain consent from the appropriate river authority. The consent procedure prescribes the location, maximum volume, and minimum quality conditions for the discharge. A number of toxic discharges were stopped. Septic tank discharges less than four feet deep did not require consent unless the discharge was directly into chalk; it was reasoned that self-purification via the top soil would take place and furthermore that no other alternative was available. All industrial effluents, including cooling water, required consent irrespective of the discharge depth.

To date 601 consents to discharge underground have been issued. Most are for domestic sewage effluents from small treatment plants. Discharges in excess of 5000 gpd include 36, and four of these are in excess of 100,000 gpd. A few sewage effluents have a consent condition that 2 mg/l of chlorine shall be present. This does not sterilize the effluents, but the numbers of bacteria are much lower than in unchlorinated effluents. Discharges of industrial wastes include 35 in excess of 5000 gpd; 17 of these exceed 100,000 gpd of which 14 are cooling water. All of the effluents of larger volume originate from conventional treatment plants and are normally of good quality.

The generally rural locations of the discharges, the large dilutions by rainfall, and the self-purification of the effluents insure that pollution is minimal -- probably less than that from agricultural sources. No routine discharge of sewage effluent underground has produced a significant deterioration of groundwater.

A few pollution incidents have arisen from spillages; however, none was serious enough to affect groundwater withdrawals. Little

can be done to prevent pollution by accidental spillages, but steps can be taken to mitigate their effect. Further actions that could be taken include: (a) formulate codes of practice on the handling, transport, and storage of potentially polluting materials, (b) amend the law to provide that failure to conform with codes of practice is equivalent to causing pollution to occur, and (c) educate the public at large, including school children, on the need to prevent pollution from occurring.

Defining the Spread of Groundwater Contamination Below a Waste Tip

by Dr. H. J. Exler, Bayerisches Geologisches Landesamt, Munchen, West Germany.

The Bavarian Geological Office has investigated groundwater pollution derived from a domestic and industrial refuse landfill operated since 1954. The landfill lies on fine to coarse sandy gravel; direct contact between the refuse and groundwater does not occur. To date 4 million m^3 of refuse and covering have been deposited over an area of 153,000 m^2.

To study pollution effects a well was drilled at the foot of the landfill and another on the upper side. A pumping test was conducted on the lower well and chemical analyses were made of water from the two wells. These showed that groundwater flowing under the landfill acquired a yellowish color, a pungent odor, an increase in temperature of 10°C, a 13-fold increase in chloride, an ammonium increase of 300 times, a permanganate increase of 23 times, and a decrease in sulfate.

To investigate the extent of pollution nine new wells were drilled. In order to minimize water analyses, standardized measurements of electrical conductivity and temperature of the groundwater were adopted. Because chloride was the predominant ion, electrical conductivity measurements allowed the path of pollution to be traced throughout the zone where organic components decayed. Temperature could only be used as an indicator near the landfill because the heat from exothermic reactions in the landfill was lost fairly rapidly.

Measurement of fluorescence under ultraviolet of groundwater was also employed to indicate organic substances.

Field measurements were made semi-monthly. Results showed temperatures were highest near the landfill, while high conductivities extended in a downstream tongue which narrowed with distance. Pollution was identified for a distance of 1350 meters.

To follow the course of the pollution ten more observation wells were drilled up to a distance of 3000 meters. Field measurements as well as chemical analyses showed that not only inorganic but also organic pollution, as evidenced by the distribution of permanganate values, traveled 3000 meters. The chloride distribution is shown in Figure 4. Nitrate measurements in the groundwater revealed that nitrate was completely destroyed where organic loading was high.

Individual measurements on particular days compared with long-term data indicated that single measurements may not be representative of the degree of pollution within the whole sampling area. A further aspect is that the dumping of household refuse has declined in favor of ash for more than a year. Organic substances as a consequence are largely absent, and it is suggested that future measurements might show a cementing effect due to conversion of the ash to calcium carbonate. This could lead to a reduction in groundwater pollution.

Comparison of these results with those from other landfills showed similar reduction, transition, and oxidation zones extending downstream. The reduction zone, simply indicated by asbestos tape (suspended in observation wells) being stained black from iron sulfide, is defined by the consumption of all oxygen through the oxidation of organic substances in the groundwater. In these anaerobic regimes nitrate reduces to nitrite and ammonium or free nitrogen gas. In one well enough methane gas was released to produce ignition. In the transition zone, where asbestos tape is stained brown by ferric hydroxide, there is the occasional availability of oxygen. Finally, in the oxidation zone, asbestos tape remains colorless, indicating that the water contains oxygen.

Results of different landfill studies also showed that the range and pattern of spreading of polluted groundwater depends upon local

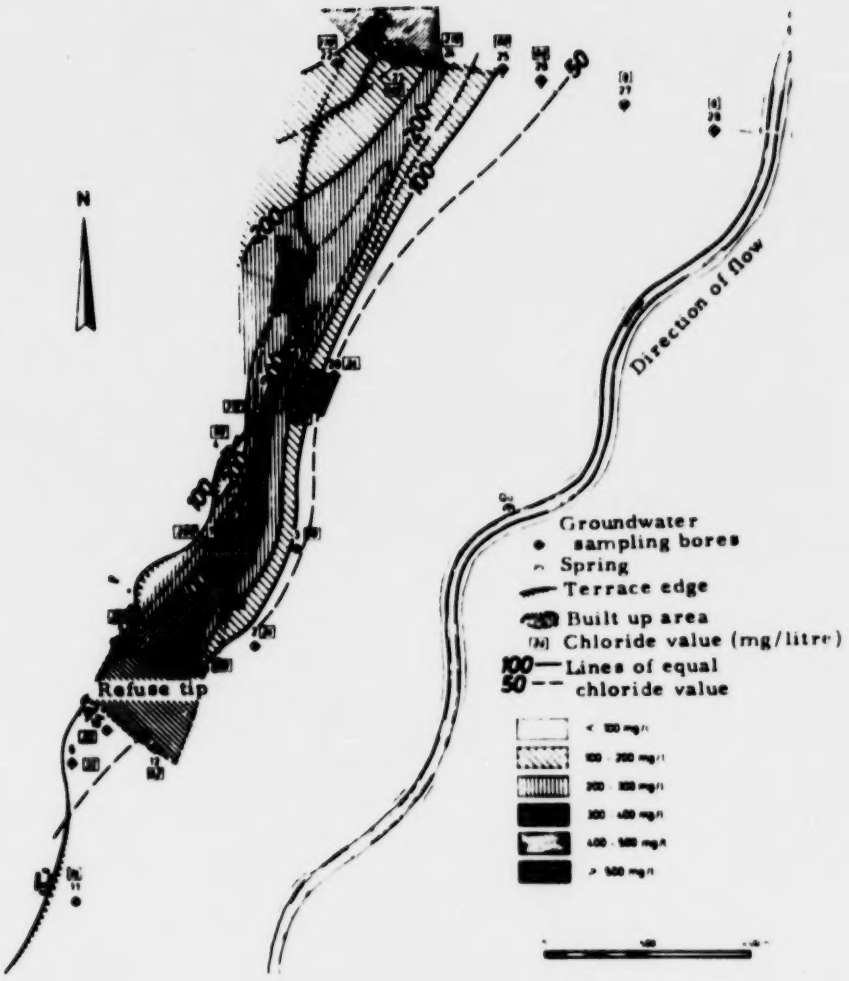

Figure 4. Distribution of chloride downstream from a landfill in West Germany.

hydrogeological conditions. Thus, hydrogeological and tracer investigations should be made before starting a new landfill.

Infiltration from Farm Silage

by H. J. Richards, Water Resources Board.

A field study was undertaken of silage liquor and of the possibility of it polluting groundwater. An existing silage clamp was selected, located on chalk (limestone) and where the water table fluctuates annually between 20 and 26 meters below ground surface. At the site soil had been removed and the chalk excavated to create a flat area of 185 m^2. Two observation wells were drilled adjacent to the clamp. The local natural groundwater has a hardness of about 260 mg/l, sulfate of 8 mg/l, total dissolved solids of 280 mg/l, and a pH of 7.8.

Silage is made seasonally by placing cut grass into the clamp in summer. This feed is used during the winter, and the clamp is normally clear in the spring. One ton of unwilted silage can produce 60 gallons of polluting effluent, and silage clamps of 300 tons are not uncommon. The silage liquor is highly noxious, having a BOD of 12,000 to 60,000 mg/l and a high phenol content.

Water samples were obtained weekly or monthly from two different depths in each well and were analyzed for phenols, sulfate, hardness, pH, BOD, COD, taste, odor, total dissolved solids, alkalinity, and permanganate value. During two seasons of measurements no relationship was shown between the quantity of the contaminants reaching the water table and the rates of natural infiltration. Vertical movement of the effluent through the chalk is very slow, perhaps 0.8 m/yr, while more rapid movement occurs through fine fissures. There is no doubt about the proportions of the effluent moving through the fissures and through the intergranular spaces. In the zone of aeration improvements in the polluting effluents are produced by filtration, adsorption, and biological degradation.

Although pollution in terms of phenols, sulfate, BOD, and COD was measured 15 meters from the clamp, its persistence beyond this distance is not known.

Nitrate Pollution of Chalk Groundwater in East Yorkshire: A Hydrogeological Appraisal

by S. S. Foster, Institute of Geological Sciences, and R. I. Crease, East Yorkshire (Wolds Area) Water Board.

Groundwater in chalk aquifers of East Yorkshire supplies a population of 500,000. Evidence of nitrate pollution is derived from periodic water analyses. During 1960-69 all water supplies had had constant and low values of 2.5 to 4.5 mg/l NO_3-N, but during 1970-72 many localities showed sharp increases with values in the range of 8.0 to 14.5 mg/l NO_3-N. An eight-laboratory determination of split samples revealed an absolute variation of more than 1.0 mg/l NO_3-N, with similar variation in repeated determinations by individual laboratories using the rapid selective ion electrode technique.

Existing evidence is indicative of appreciable nitrate pollution. The cause for concern is not only the present NO_3-N concentrations but also their widespread and apparently rapid rate of increase. There seems little doubt that the pollution has its origin in agricultural activity. Although a survey of agricultural practices has not been undertaken, it appears that certain practices in specific hydrogeological settings lead to the greatest hazard.

An interdisciplinary research program involving hydrogeochemical and hydrogeophysical aspects is probably required. In subsurface environments oxidation, reduction, dilution, and dispersion will influence the fate of the infiltrating pollutant. The hydraulics of saturated flow in the East Yorkshire Chalk are well understood; natural flow rates can be of the order of 50 m/day in this fissure-flow formation. Unsaturated flow in the chalk is a subject of great contention. It has been suggested that intergranular seepage dominates with downward velocities as low as 0.88 m/yr, while tritium age determinations indicate a dominance of pre-1953 precipitation. If it is assumed that the bulk of the current nitrate pollution is of a similar age, then it can be inferred that further increases could occur because the rate of application of nitrogeneous fertilizers has subsequently increased.

Agricultural Fertilizers, Slurry Disposal, and Nitrate Pollution of Groundwaters

By Dr. J. R. Burford and B. Pain,
University of Reading.

Available data show that agricultural fertilizers probably do not produce significant nitrate pollution of groundwaters on well-managed farms. There is, however, a trend toward heavier applications of fertilizers under intensive farming or stocking systems, and therefore an increasing risk of significant pollution.

Nitrate in the soil is easily leached due to its high solubility and the lack of adsorption by colloidal surfaces. Nitrate in the soil originates from rain or fertilizer, or by nitrification of ammonium ions. The source of the ammonium ions may be ammonium fertilizer, urea, or organic matter. Nitrate is removed from the soil by plant roots, assimilation by micro-organisms, or dissimilation (utilization by denitrifying organisms). The net result of nitrate additions to and removals from the soil water determines the nitrate content of the percolating water reaching the water table.

Present evidence indicates that all significant drinking water supplies in Britain contain less than 10 mg/l NO_3-N and that they will probably remain at this satisfactory status until the end of this century. It is difficult to assess agricultural levels of nitrate to groundwaters due to climatic, soil, and chemical effects. Localized high concentrations of nitrate in drainage water result from temporary overloading of the capacity of the soil-plant system to absorb nitrate. Denitrification tends to remove nitrate from groundwater; the reason for small amounts of nitrate in most groundwaters is the lack of available organic substratas.

Animal dung and urine can cause nitrate pollution problems, particularly where livestock are confined to feedlots. In areas where livestock are concentrated this excreta accumulates as slurry, which is potentially a valuable fertilizer but must be properly spread on the land to avoid pollution. Appreciation of the magnitude of the problem can be obtained by realizing that the production of undiluted slurry from livestock in the United Kingdom totals 111 million tons annually. Nitrates are readily taken up by growing crops, and the risk to water pollution can be reduced by balancing the quantity of nitrogen

applied with crop requirements. Slurry spreading should be avoided where no crop is removed, and similarly, water pollution is more likely to result from spreading slurry during winter months when rainfall exceeds evapotranspiration. At present little is known of the contribution of livestock slurries to nitrate concentrations in the groundwaters of the United Kingdom.

There is probably very little direct leaching of nitrate-N from inorganic fertilizers applied at rates of up to 130 to 270 lb N/acre in well-managed agricultural enterprises. Yet, mineralization of N in readily decomposable organic matter and plant residues may occasionally result in drainage water containing moderately high levels of nitrate. There seems little hope that such mineralization can be completely controlled, and it is not yet of great overall significance since the general concentrations in groundwaters are within acceptable limits.

Pollution Affecting Wells in the Bunder Sandstone

by Dr. G. D. Nicholls, Edgar Morton and Partner.

Groundwater pollution may be direct (related to the nature of the pollutant) or indirect (cause and effect may be concealed by a sequence of events and interactions spread over a time span of years), widespread or local, and short-term or long-term. Vigilance over groundwater quality is necessary because pollution prevention is better than purification. Our true objective should be identification of potential hazards before pollution develops.

Local short-term pollution incidents include accidental releases of noxious liquids into porous soils overlying groundwater supply areas. The recent spillage of molten sulfur from an overturned tanker trucker illustrates the situation; fortunately, here the sulfur solidified and could be easily excavated without harming the groundwater. A different example is that of a farmer who excavated an area to form an irrigation reservoir. The reservoir penetrated the Bunder Sandstone and was filled with nearby stream water. Subsequently, municipal water supply wells one-quarter mile away showed large increases in coliform.

After the stream diversion was stopped by local authorities, the bacteriological quality of the water improved.

The existence at ground surface of waste dumps may result in a slow and progressive pollution of groundwater. Coal mine dumps are good examples because rainwater seeping through them emerges with high dissolved mineral contents. A well in close proximity to a coalfield near Doncaster illustrates the effect of seepage from the coal dump through the Bunder Sandstone. When drilled in 1919, the well had water with a total hardness of 126 mg/l and a chloride of 13 mg/l. By 1932 these values had increased gradually to 414 mg/l and 337 mg/l respectively, and the well was abandoned. By 1965 these values reached 2060 mg/l total hardness and 2925 mg/l chloride. Besides the high mineral content of these polluting waters, they also have a negative oxidation potential which results in the leaching of iron from any iron-bearing rock. Thus, a nearby pumping station has recently measured iron contents in its groundwater of 0.12 to 0.68 mg/l. Additionally, a nearby vegetable cannery and a piggery discharged their organic-rich wastes onto outcrops of the aquifer.

Indirect pollution can be shown by the long-term effects of spraying vegetation with insecticides in organic bases such as xylene. Underlying soils on sandstone are often acid, implying deoxygenation of percolating rainwater, so that the solvent hydrocarbons are carried down to the aquifer before oxidation. Flowing laterally with the groundwater and gradually mixing with more oxygenated water from elsewhere in the basin, the hydrocarbons will oxidize to produce carbon dioxide in the water. This carbon dioxide enriched groundwater would be corrosive to calcium carbonate cement in the sandstone and would be particularly effective to joints and fissues through which the water is moving toward wells. Attack on the cement might lead to increased chloride and sulfate contents by solution of films of these minerals around sand grains. These changes in the chemistry of the water might develop over an elapsed time of two to five years after spraying of the insecticide.

This situation has perhaps even more striking effects. Liberated sand grains could move through the aquifer and eventually appear in the pumped water. Air mixing with hydrocarbons by water table fluctuations may produce carbon dioxide in solution in the groundwater. The gas might, after pumping, come out of solution in a multitude of minute bubbles, giving the water a most undesirable milky appearance.

Protection of Aquifers Against Petroleum Pollution in Switzerland

by Prof. Dr. Th. Dracos, Eidgenossiche
Technische Hochschule, Zurich, Switzerland.

Alluvial valley aquifers provide the most important sources of water supply in Switzerland and are subject to pollution by petroleum products due to increasing motorization and oil heating. In 1967 the Government issued regulations to protect groundwater against possible pollution and ordered studies to analyze the movement of petroleum products in aquifers. Results of the studies showed that bulk migration of oil occurs in the capillary zone and that the migration stops after a residual saturation has been reached. Thus, in the case of an oil spill, the pollution remains within certain limits; however, this pollution may linger for decades and can affect the quality of water through its soluble elements.

A new railway shunting yard being built near Zurich overlies a major water supply aquifer with a water table five meters below ground surface. It was specified that no spillages from tank cars should reach the groundwater and that the infiltration of precipitation should not be reduced below that occurring naturally. Active protective measures instituted included having emergency equipment available so that spilled oil products could be recovered before they infiltrated into the soil. Any polluted soil should be removed layer by layer to prevent movement downward to the water table.

To slow infiltration a delaying layer of semi-permeable material was built under the railway ballast. Experiments using oil and gasoline were conducted to relate saturation distribution as a function of time. Results, shown in Figure 5, led to a design thickness of 1.5 meters for a layer having an average permeability of 4×10^{-5} cm/sec.

To prevent groundwater pollution from a refinery overlying a developed aquifer in Cressier, all used and polluted surface waters are collected and led to a purification plant. Leak-proof collecting basins are built to protect the groundwater at all critical plant locations. Because groundwater pollution in the refinery area cannot be ruled out entirely, seven wells were drilled. These are pumped so as to maintain an inward flow of groundwater beneath the refinery, thereby intercepting any pollutants reaching the water table. To minimize

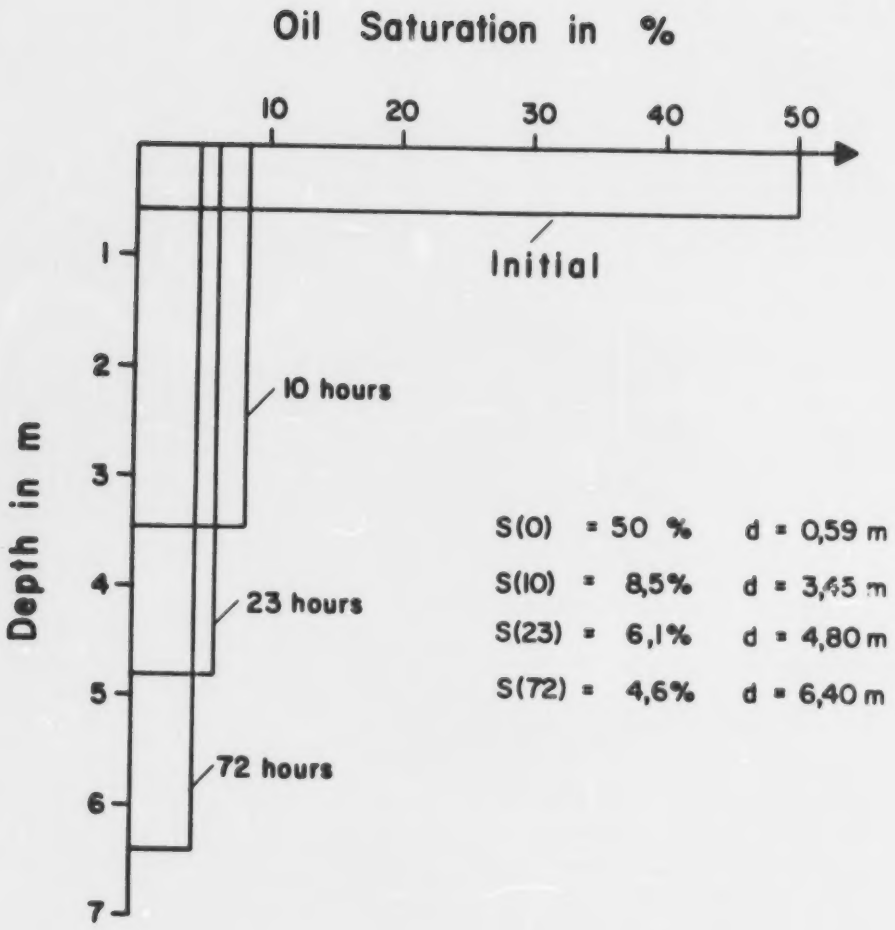

Figure 5. Experimental results from Switzerland on the distribution of oil in soil as a function of time.

infiltration from an adjacent stream to the wells, subsurface impermeable screens were built. In addition, other standby wells were drilled and equipped with pumps to operate in emergencies.

Only rarely are protective measures completed in advance. For existing installations it is often possible to construct a subsurface impermeable screen of concrete and bentonite around the endangering area. If a low-permeability layer exists at a shallow depth, the screen should reach this layer. If the permeable layer is deep and the water table is shallow, the screen should extend 3 meters below the lowest groundwater level. By so doing, the screen forms a barrier against the spreading of oil but lets the groundwater pass. Wells should be constructed inside the screened area for operation in case of an emergency.

In spite of all such precautions, it is not possible to prevent completely the infiltration of petroleum products caused by accidents. One tries to remove the contaminated soil, but this is not always possible near buildings. Pumping wells aid in recovering at least part of the spilled oil products and in limiting the spread of the oil. Such measures are expensive, last too long, and are difficult in nonhomogeneous soils.

A Recent Case History of Groundwater Pollution by Organic Solvents

by J. B. W. Day,
Institute of Geological Sciences.

A burst water main on a factory site led to the discovery of severe groundwater pollution. Excavation to repair the main revealed an aromatic liquid, which upon analysis was found to contain organic solvents, mainly ketones and alcohols, as well as abnormally high sodium and potassium. Nearby public water supply wells were immediately closed, and water samples from these showed ketone concentrations up to 8 mg/l.

Examination of the factory premises revealed that the source of pollution was probably leaking underground effluent drains. The

resulting investigation established that severe pollution was restricted to one portion of the factory containing a number of organic liquid storage tanks. Shallow pits and auger holes provided sampling points. Examination of a drain indicated that the main source of trouble was fracturing due to compaction and subsidence of the fill material in which the drains were laid.

After the defective drain had been bypassed, suction scavenge pumping was carried out from eight pits in the affected area in an effort to clear the body of polluted groundwater which appeared to lie mainly at relatively shallow depths. There was a tendency for the natural groundwater discharge to have a clearing effect, and it was hoped that bacterial degradation would play a part. Samples from a pit sunk to the underlying chalk were found to have potassium concentrations up to 36 mg/l.

Scavenge pumping from pits within the most severely polluted area continued for more than a year. The solvent content of the groundwater gradually reduced, and at the end of this time samples from the water supply wells (still not in use) showed no contamination. All underground effluent drains were replaced by a pumped overhead effluent system.

The Impact of Organic Pesticides and Herbicides upon Groundwater Pollution

by Dr. B. T. Croll,
The Water Research Association.

Groundwater pollution problems can arise from the use of pesticides and herbicides; however, hazardous concentrations seldom occur due to adsorption on soil and plants and degradation by soil bacteria. Organic pesticides and herbicides have been detected in many parts of the environment, and organo-chlorine insecticides in particular occur almost universally. Contamination of water by these chemicals has not usually been caused by their correct use in agriculture, but by misuse, accident, or as industrial effluent.

Toxicity of pesticides and herbicides in water is of prime importance when considering effects on humans. Acceptable intakes are assessed

for experiments on animals, after which large safety factors are applied in transferring these data to man. Many organic chemicals can give rise to unpleasant tastes and odors at levels well below 1 mg/l. Reactions with other materials may produce even greater problems; the obnoxious odors of chlorinated phenols are a good example. Some compounds also produce color in water at low concentrations.

Organo-chlorine insecticides, including DDT, Endrin, and Lindane, may persist for long periods in groundwater. Only very low concentrations are likely to be found in groundwaters; however, these may easily reach permissible maxima. Of eleven insecticides leached through eight soil types, only Lindane was eluted from a high organic soil. The higher the clay and organic matter, the smaller the leaching of the insecticides. DDT may persist in soil for longer than 20 years, and similar persistences may be expected in groundwater although there is little information from aquifers. An examination of 74 different groundwater samples in Kent, England, failed to detect organo-chlorine insecticides in any sample. These insecticides have been detected in isolated instances in the USSR, Switzerland, and the Chew Valley of England.

Organo-phosphorous insecticides are generally much less persistent in soil than the organo-chlorine, being measured in days or weeks rather than years. Also, the phosphorous compounds are generally more water soluble than the chlorinated insecticides; therefore, they would be expected to leach through the soil more readily. A study of six organo-phosphorous insecticides in four soils showed that they all leached through the soils, the rates being slower with high clay content soils. The percentage of recoveries of these insecticides varied depending upon the breakdown in the soil; biological activity was the most important factor in determining the breakdown. No data was available on the movement or persistence of these insecticides. There is only one recorded instance of groundwater pollution by organo-phosphorous insecticides.

Carbamate compounds are used both as herbicides and insecticides, are generally of low toxicity, and do not build up in the body. These materials are relatively new and little is known about their environmental effects. No residues of carbamates have been recorded in groundwaters.

The problems associated with the phenoxyalkl acid herbicides are of taste and odor and not toxicity. Some of these acids are are applied

as esters; these rapidly break down into the corresponding acids, which are extremely water soluble. No background levels of phenoxyalkl acids have been detected in groundwaters. Two notable incidents of groundwater pollution due to 2, 4-D in industrial effluents have been reported at Montebello, California, and the Rocky Mountain Arsenal, Colorado.

Most organo-chlorine insecticides are not affected by normal water treatment methods. Treatment with activated carbon is the only effective method for removing the majority of these materials from water; the same applies to phenoxyacetic acid herbicides and sometimes so for organo-phosphorous insecticides.

Computer Simulation of Pollution Front Movement

by J. P. Sauty
Bureau des Recherches Geologiques
et Minieres, Orleans, France.

The purpose of the calculation is to compute the propagation of a pollution front in an aquifer. Assumptions involved are that dispersion is negligible, molecular diffusion does not occur, the pollutant is not adsorbed by the porous medium, and the velocity field is not disturbed by the advance of the front. The computer program yields the streamlines for steady flow. The aquifer may be confined or unconfined and homogeneous or not. The displacement speeds along streamline trajectories allow the position of the pollution front to be defined at successive time intervals.

Three aquifer examples are presented. The first is of an undeveloped aquifer with an impermeable boundary on one side and a river on the other. Pollution from the river is followed through the aquifer. The second example involves the same aquifer but with a group of wells pumping long enough so that flow is steady when pollution occurs. As shown in Figure 6, the pollution front does not reach the continuously pumping wells until the eighth day and water pumped from the wells is not totally polluted until after about 100 days. The third example includes an aquifer bounded by a lake and a river, containing a recharge pond, and having a pumped wellfield.

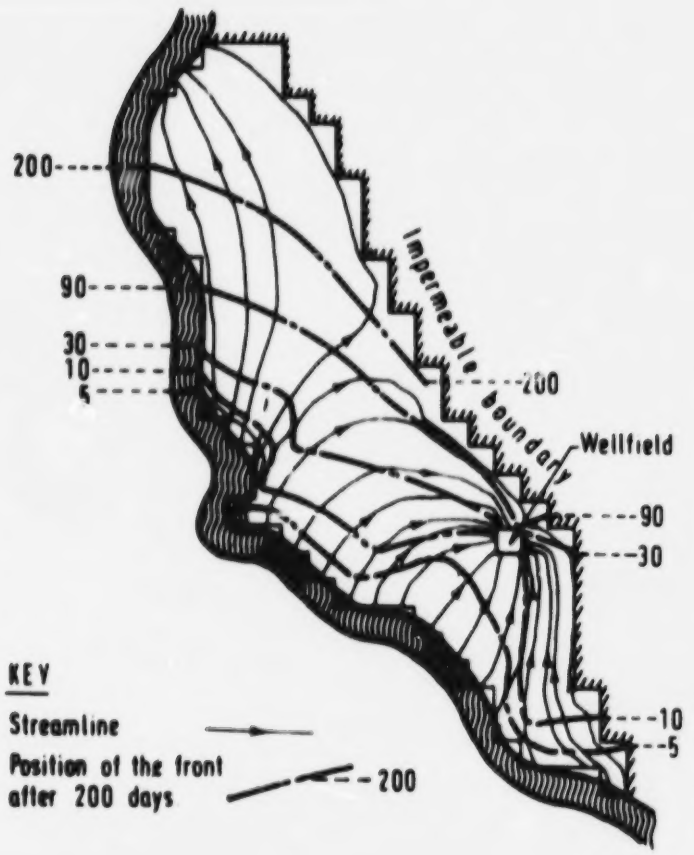

Figure 6. Computer results from France showing movement of pollution from a river through an aquifer to a well field.

Similar considerations would permit following the movement of pollution limited in space and time. A river polluting an aquifer, as in Fig. 6, for a short time would create a band of pollution advancing toward the wells.

The principle adopted for the calculation was to construct streamlines from various present starting points on the boundaries. Each streamline is approximated as a segment of a square in which the transmissivity and the central head values are known. The direction of movement within each square is found as the resultant of the head gradients, and the transit line is computed using Darcy's law.

It should be noted that the simplified hypotheses adopted lead to a pessimistic evaluation of the maximum concentration of the pollutant. The phenomena neglected in the assumptions would all tend to reduce the intensity of the concentration curves.

Flow Tracing Using Isotopes

by D. B. Smith,
United Kingdom Atomic Energy Authority.

Radioactive isotopes provide valuable and unique techniques for investigating many facets of underground water and pollutant movement. Tritium is unique in providing an almost perfect tracer for groundwater movement. Studies involving radioisotopes may use an added tracer or the "natural" very low radioactivity of tritium or Carbon-14.

Any of several radioisotopes can be selected as a tracer. Tritium is incorporated within the water molecule, is not subject to adsorption, and thus provides an excellent tracer for water. Unfortunately, it cannot be detected in the field using portable equipment. In-situ measurement of a tracer in groundwater is very desirable. Gamma-ray emitting tracers for this purpose include Bromine-82 and Iodine-131. In clayey strata or areas of high ion exchange capacity, where a negative answer showing the traced water has not come to a particular sampling point is of great importance, tritium is the only reliable tracer to use.

Several different radioactive tracer techniques have been developed for field use. Water tracing and the interconnection of water supplies can be studied by means of the high sensitivity of radioisotope detection. Well investigations involve labelling the column of water in a well followed by logging of the tracer to identify horizons of flow. Similarly, a pulse of a tracer in a well can be used to measure the vertical flow velocity and identify points of entry and exit of water. The single well technique can be used to evaluate groundwater velocity; the tracer is injected into the well, is allowed to move with the natural velocity for a predetermined time, and is then recovered by pumping the injection well. The velocity and direction of groundwater flow can also be measured by other specialized instrumentation in wells.

Examples of field studies using radioactive techniques in the United Kingdom are cited. These include tracing simple near-surface water movement, following near-surface water movement in the unsaturated zone, measuring a river contribution to groundwater, evaluating lake bed leakage, and determining groundwater movement in a mine.

Safety considerations are important when a radioactive tracer is in concentrated form before injection. With tritium, only precautions against ingestion and inhalation are necessary. Investigations should use the minimum amount of tracer compatible with the needs of the study. Dilution of a tracer in groundwater insures that high concentrations cannot occur in water supplies.

Tritium occurs naturally in the atmosphere and enters the hydrological cycle as rain. Originally it was expected that natural tritium measurements of groundwater could be used to "date" the water using the 12.3-year half-life. However, with thermonuclear testing occurring sporadically since 1954, tritium concentrations in rainfall have varied by orders of magnitude. With this complex input of tritium over 18 years, quantitative interpretation of measurements is difficult.

Natural tritium has also been employed to study the rate of downward movement of water in a chalk aquifer. Cores were analyzed for tritium; peaks with depth were found to correspond to known atmospheric peaks. These results suggest that intergranular flow of water is very slow, approximately 4 meters in 8 years.

A single measurement of natural tritium in groundwater can indicate whether the water is of pre-1954 or more recent origin. Repeated measurements over time could show whether old and recent waters were mixed together. Measurement of the Carbon-14 content of the bicarbonate dissolved in water is capable of measuring the "age" of waters back to about 25,000 years and may prove useful in separating connate waters from recharged groundwater.

Local Studies of Miscible Pollutions of Groundwater: The Single Well Pulse Technique

by Dr. J. J. Fried, Ecole des Mines des Paris,
and P. C. Leverque, D. Poitrinal, and J. Severac,
Laboratoire de Radiogeologie du Bassin d'Aquitaine,
Faculte des Sciences de Bordeaux.

The propagation of pollution in stratified soils depends upon local parameters. A low-cost method for determining these parameters involves filling a completely penetrating well, screened throughout its entire depth, with water labeled by a radio-tracer at constant concentration. This water is injected into the aquifer by fresh water and subsequently is pumped back into the injection well. At each level the tracer concentration is recorded with respect to time. Measurement of the concentrations can be used to evaluate the relative permeabilities of various strata and the longitudinal dispersion coefficient.

Different radioactive tracers have been tried, but Iodine-131 and Bromine-82 are generally used. The required tracer activity is very low. The tracer is mixed in about 4 m^3 of water for a well 30 meters deep. These tracers do not present any danger to the field staff or the environment, have good detectabilities, and do not modify the water density. Radioactivities are measured by a scintillation probe. The impulse sent by the probe though the supporting cable is received by an integrator and a counting scale connected to a recorder. Properties of the probe have been investigated for its power of resolution and its volume of influence.

The observation well used for the measurements must have screens with greater than 20 percent openings through the entire aquifer thickness. The screen is covered with nylon linen; no gravel pack may surround the well. During a test flow rates must be kept small, while logs of the well by the probe are made as often as possible. Some 50 such tests have been conducted for a variety of purposes.

A qualitative evaluation of permeability is obtained by the relative activity found in the well as a function of depth; higher activity zones are associated with higher permeabilities. The longitudinal dispersion coefficient is computed from the dispersion equation. The aquifer is assumed to be homogeneous, horizontal, and consisting of independent strata. Tracer quantities are assumed to be small enough so that the density and viscosity are equal to those of fresh water. Solutions to the equation can be obtained either from a semi-analytical formula or by direct simulation and curve fitting.

From an experimental viewpoint the method has the advantages that most (85 to 95 percent) of the radioactive tracer is pumped out of the aquifer and that shorter-lived isotopes can be employed; both factors act to avoid any underground pollution.

Deep Well Injection of Liquid Waste

by J. S. Mokha,
University of Tulsa, Oklahoma, USA.

The storage capacity of some geological formations is a natural asset that has been utilized for many years, primarily for the disposal of oil-field brines. In recent years injection wells have been used for subsurface storage of natural gas and permanent disposal of industrial wastes. Subsurface disposal contemplates pumping liquid waste through wells into permeable formations having adequate porosity to accept large waste volumes at low injection pressures. Wastes, once underground, displace nearly equal volumes of natural formation fluids. There are no empty formation pore spaces; fluid movement occurs due to pressure gradients with the formation remaining saturated at all times.

Subsurface disposal can produce pollution problems which are difficult to discover and hard to rectify. Definite geological conditions are necessary for a successful deep-well disposal system. Two of the most vital are (1) the disposal formation should have sufficient porosity, permeability, and areal extent to accept wastes at safe and practical injection pressures, and (2) the disposal formation should be vertically below the level of fresh water and should be confined vertically by impermeable rocks in order to prevent the pollution of fresh water aquifers and interference with any other natural resources.

The injection formation would normally be sandstone, limestone, or dolomite; rocks with solution or fracture porosity are preferred. Rocks which have very slight permeability and could serve as confining layers (aquicludes) include shales, clay, slate, anbydrite, gypsum, and siltstone. The minimum depth of burial can be considered that at which a confined saline water-bearing zone is present; it may range from a few hundred to several thousand feet. Other considerations in the determination of site suitability are the presence of high pressure and temperature in the injection zone that may make injection difficult or uneconomical, local earthquakes that can cause movement along faults and damage to wells, the presence of abandoned and improperly plugged wells that provide a means for escape of injected waste to groundwater aquifers or to the surface, and the mineralogy of the injection zone and chemistry of native waters which may determine the injectability of a specific waste.

The suitability of waste for injection must be determined to avoid plugging of the formation pores and consequent loss of intake capacity. Plugging is normally caused by suspended solids and gases initially in the waste liquids, precipitation reactions, production of gaseous reaction products, development of reaction coatings, dispersion of clay minerals, or bacterial growths.

Most injection wells are drilled by the rotary system. The number and type of casings depend upon local hydrogeological conditions. For corrosive wastes a corrosion-resistant inner injection tube is placed inside to protect the injection casing. Mechanical and/or fluid seals, such as shown in Figure 7, isolate the annular space from the disposal formation and the liquid waste. Surface equipment associated with an injection well usually consists of centrifugal pumps together with waste collecting, storage, and treating facilities.

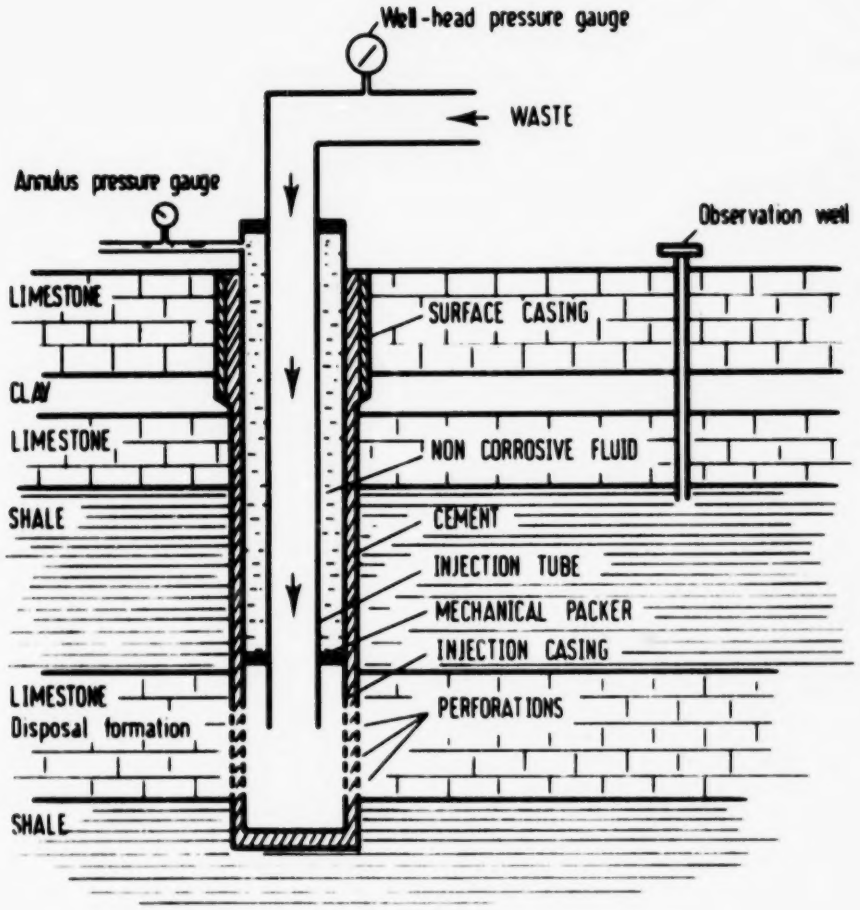

Figure 7. Design of a waste disposal well with fluid and mechanical seals.

Deep-well disposal operations should be monitored to obtain performance data, detect failure of well casing or cement, assure safety of groundwater and other resources, and determine the movement of injected waste. The following parameters are normally monitored: (a) rate of injection, injection pressure, and composition of injected material; (b) pressure and composition of the fluid in the annular space between the injection tubing and well casing; and (c) pressure and water composition in observation wells. Observation wells which terminate in the confining layer of a freshwater aquifer just above it can be useful in detecting leakage from the disposal horizon and should be carefully monitored for pressure and water quality.

Well Screens — Some Notes on Materials

by E. Elliott,
Stainless Steel Development Association.

The two principal causes of reduction in flow rate through well screens are growth of incrustations and corrosion of the screen. To resist corrosive attack materials such as copper alloys, aluminum, plain carbon steel, stainless steel, plastics, and glass reinforced plastics have been used. In general, considerations of cost and strength have led to the choice of stainless steel screens, either as a fine-wire wound screen or as a machine-slotted tube.

It is the chromium in stainless steel which is principally responsible for their high resistance to corrosion. For well screens austenitic stainless steel is employed; this contains 17 to 19 percent chromium and 7 to 12 percent nickel. The nickel content improves the formability and the weldability of the steel.

For wells in contact with sea water or other highly corrosive waters, an austenitic stainless steel containing an addition of 2.5 percent molybdenum is recommended to avoid pitting.

Unclogging of Boreholes

by G. R. S. Stow,
George Stow & Co., Ltd., Henley-on-Thames.

Wells may require unclogging initially as part of the construction procedure. Removal of fines in sands and gravels by swabbing, jetting, back-washing and surge pumping through the screens is practiced to unclog the formation around the screen and thereby increasing the specific yield of the well. Swabbing is effected by a plunger reciprocated in the well. Jetting usually involves two or more horizontal high pressure water jets with the nozzles close to the wall of the screen. Back-washing and surge pumping involve pumping down at a high rate, stopping the pump, and allowing the water to rise to near the initial level.

Acidization can be used to improve greatly the yields of limestone aquifers by enlarging joints and fissures. For best results hydrochloric acid should be rapidly injected under pressure, which is maintained by the CO_2 generated. This causes the acid to flow outwards from the well and to enlarge fissures and joints for a considerable distance. Using several tons of hydrochloric acid, increases of several hundred percent in well yield are not uncommon.

With time wells may become clogged by encrustations, including deposition of calcium carbonate or precipitation of iron. The usual treatment is the introduction of hydrochloric acid, and after some hours, contact swabbing and surge pumping followed by initial clearance pumping, then Calgon injection, followed by further swabbing or surge pumping and final clearance pumping.

Sand inflow to wells from soft fissured sandstones is sometimes a problem. Fine screens or filters tend to become clogged with the fine sand and cause reduction in well yield. It is suggested that the best way of handling the problem is to spread the extraction among several wells and thus reduce the velocity from joints and fissures so that sand inflow is negligible.

The use of explosive charges is seldom effective in improving well yields.

SECTION 3

SUMMARIES OF CASE HISTORIES

Pollution Prevention at Two Refuse Tips

by G. M. Swales and A. S. Davidson,
East Surrey Water Company.

Construction and operation of two landfills are described; effluents, which are highly polluted liquors, are drained from the area to minimize infiltration to groundwater. There is no evidence of deterioration in bacteriological or organic quality of water from wells within one-half mile of the landfills; however, changes in hardness, chloride, sulfate, and nitrate have been noted. Potassium is the most useful indicator for tracing pollution from landfills. Anaerobic landfill effluents may cause a musty taste and odor in some underground water supplies.

Dredge Mining for Rutile — Effects on Water Quality

by Dr. R. Herbert,
Engineering and Resources Consultants Ltd.

Dredge mining of an aquifer in Australia for rutile and zircon produced tailings deposits underlain by a slimes layer. Bacterial attack on the organic matter of the slimes led to changes in groundwater quality, namely increases in total dissolved solids, color, and acidity. A total of 44 observation wells have been installed to monitor groundwater pollution. The mining company has been instructed to dispose of mining slimes outside of the aquifer boundaries.

Case Histories of Some Phenolic Pollutions in Essex

by R. Aspinwall,
Essex River Authority.

In 1954 phenolic pollution was discovered in industrial wells drilled in chalk, and it persists to the present. The contaminant was carburretted water gas tar, believed to have originate' from a nearby water gas manufacturer. To control pollution abandoned wells on the site have been sealed and a scavenger well was drilled. This well, however, has only removed 4000 gals of contaminant.

In 1969 some 700 tons of naptha were reported lost from a petroleum storage area buried in dry chalk. The contaminant flowed through fissures and appeared within one month in water of a nearby abandoned quarry. Monitoring of 30 wells was instituted on a daily basis. A trench and a sump were constructed and pumped to intercept the naptha. The contaminant finally ceased after 20 months of pumping.

Three separate spills of over 400 tons of leaded petroleum spirit entered flood plain gravels; subsequently, an explosion occurred in the basement of a nearby house. Investigation showed that petroleum gases above the water table had migrated into the basement during a high water level period. Efforts to remove the pollutant by pumping were largely unsuccessful due to the low permeability and thinness of the gravels.

Petroleum Pollution at Great Hospital, Norwich

by Prof. B. M. Funnell,
School of Environmental Sciences,
University of East Anglia.

A light petroleum oil was found in a hospital boiler house, located in a deep concrete-lined pit, and one explosion occurred there. A deep pit dug nearby also encountered oil. No remedial action has

been taken, but proposals include cutting a drain across the course of the pollution stream so that the oil flow can be intercepted and removed by pumping. The responsibility for the pollution is not yet determined at law. The immediate danger is not to water supply but of fire risk; fortunately, the water table is 1 to 2 or more meters below ground surface.

Studies for the Prevention of Oil Pollution near Bratislava, Czechoslovakia

by A. Hunter Blair,
The Water Research Association.

A study was undertaken of the prevention of pollution to a new groundwater supply source to be developed south of Bratislava on an island between the Danube and Little Danube Rivers. The potential pollution source was an adjoining oil refinery. Analog and digital model studies were made of several arrangements of wells and of pumping rates which would create a depression in the water table in the vicinity of the refinery. Such wells would isolate any oil leakage and would permit a mixture of oil and water to be removed from the ground.

Pollution of the Flood Plain Gravels by Gas Works Waste

by Mrs. H. P. Toft,
Lee Conservancy Catchment Board.

Gas works wastes, including tar acids, sludge from sulfate settlement pits, and oil from gas holders, were deposited in an old pit in the lower Lee Valley from 1905 to 1967. The liquid wastes moved through the gravels causing groundwater pollution over a wide area. Groundwater pollution has been known since 1935, has caused a fire, and has contaminated a nearby stream. Test holes showed

that the aquifer is polluted down to 6 meters, the depth of the underlying chalk. Remedial measures were confined to prevention of further stream pollution. No attempt has been made to remove the oil by pumping. The gravel aquifer is not developed locally, and there is no evidence of pollution of the chalk.

Pollution of a Spring Source by Silage Liquor

by Bristol Waterworks Company.

Water from several springs is piped to the Bristol waterworks. The springs are located in limestone, and spore tracing has shown that they are fed by underground drainage from sink holes. In 1969 one spring was polluted by silage liquor discharged through a drain into a nearby sink hole. During the pollution incident the water smelled of silage and had a maximum phenol content of 0.04 mg/l. The first hint of pollution was a chlorophenol taste in the chlorinated water. Field inspection led to discovery of the cause of pollution, and discharge of silage liquor was stopped.

Saline Underseepage Problems at Chowilla Dam

by E. T. Haws,
Engineering and Resources Consultants Ltd.

The proposed Chowilla Dam in Australia would force highly saline groundwater into the downstream Murray River irrigation channel. The underseepage would occur through a sandy aquifer 37 meters thick. Pump tests of wells were used to determine aquifer permeability, and samples of the groundwater showed salinities averaging 30,000 mg/l. Various analog model tests were conducted to devise a system of relief wells for intercepting the saline water before it flows into the irrigation channel. The salt water would be pumped to evaporation ponds.

GE73TMP-1

Saline Pollution of Underground Supply at Leicester Lane Borehole

by South Warwickshire Water Board.

Groundwater pollution of a water supply well was discovered and is thought to be caused by leaching of salt from a nearby highway depot stockpile of rock salt. The aquifer is a sandstone with a depth of 120 feet. The pollution caused significant increases in total dissolved solids, hardness, chlorides, and nitrate in the water. Control measures include covering the salt pile with polythene sheeting, constructing a concrete holding bay, and abandoning the well.

Three Case Histories of Groundwater Pollution in Brighton Chalk

by S. C. Warren,
Brighton Water Department.

Bacterial pollution of groundwater was discovered at a pumping station when the pumping rate was increased. Daily water samples from nearby wells and a river were examined bacteriologically and chemically. Water quality fluctuations were related to pumping rate, water table levels, and tidal height of the river. Observations demonstrated that pollution must originate from cesspools leaking into the chalk aquifer. To combat the pollution the village has been sewered.

Seawater intrusion of a coastal chalk aquifer occurred during each summer season. Investigations of tides, groundwater levels, and pumping rates in two nearby pumping stations were made. Using $(NH_4)_2SO_4$ as a tracer, it was found that saltwater moved through fissures between the two stations. Depth samples in a well also confirmed a chloride gradient of 83 mg/l to 2000 mg/l from top to bottom. Salinity is now controlled by rearrangement of the pumping pattern together with an importation of supplemental water from inland stations.

Groundwater pumped from a well in a chalk aquifer and located 120 feet from a small lake showed zygnema, a filamentous alga, and other organic debris similar to that found in the lake water. The biological pollution is believed to result from acidization and test pumping of the well at a high rate, thereby clearing a blocked fissure connecting with the lake. The action to be taken consists of developing an alternative water supply from springs feeding the lake.

Case Histories of Groundwater Pollution in the Essex Water Company's Area

by The Essex Water Company.

Over the years there have been several instances of concern where solid wastes were dumped near water supply wells in South Essex. During World War II a leakage of gasoline or paraffin caused certain deep wells to acquire an oily taint that persisted until 1954. The water company opposed at three different times the dumping of industrial wastes which could have affected wells.

Picric acid in wastes from an explosives manufacturer during World War I caused a yellow tint in a nearby well penetrating a chalk aquifer. Pollution, amounting to 0.7 mg/l picric acid, persisted until 1955 when the well was abandoned. Chlorination and coagulation were not effective in removing the color; activated carbon treatment was only partially successful.

Groundwater polluted by oil was pumped from a well in a chalk aquifer located 700 yards from an oil storage installation. A spillage of petroleum at a rail loading terminal resulted in noxious fumes rising from the ground under dwellings several hundred yards distant. A new oil storage installation was constructed adjacent to an old chalk quarry; a grout curtain was constructed to a depth of 10 feet below the water table to prevent oil pollution entering the quarry through the underground.

Two wells located 500 yards from the Thomas Estuary are affected by saline intrusion. Chloride contents of water samples were 380 mg/l and in excess of 1000 mg/l. The sea water is believed to

enter one well from a damaged casing and then to migrate through lower water-bearing strata to the other well. To combat the intrusion efforts were made to grout one well, but this proved unsuccessful. Now the damaged well is pumped to waste, while the other well supplies potable freshwater.

Legal and Technical Aspects of Groundwater Pollution Control

by D. D. Young,
Essex River Authority.

The various legal controls available with regard to waste disposal by landfills in the Essex River Authority area are reviewed.

Hydrogeological factors involved in the prevention of groundwater pollution by domestic refuse are discussed. Disposal of wastes into clay and dry gravel strata are generally satisfactory; however, wet gravel and chalk can cause pollution for long periods of time. Marshland areas are relatively safe in relation to groundwater due to the low permeability of silty deposits overlying water-bearing strata.

SECTION 4

NOTES ON THE DISCUSSIONS

During the discussions at the conference, the author made notes on certain opinions or facts that were stated. The substance of the comments noted may be of interest; therefore, the following numbered sentences and paragraphs summarize selected comments from the discussions. No effort was made to identify individual speakers.

(1) A representative from the Department of the Environment of the British government raised the question as to whether the reason for limited government regulations of groundwater as compared to surface water may be due to the fact that groundwater pollution is not as important.

(2) In the first session and several times thereafter, the idea of protection zones being established around groundwater supply installations to prevent groundwater pollution was mentioned. Such land use zones can be defined from geologic and hydrologic factors and have been employed in West Germany and the Soviet Union.

(3) Some 19 million people in England derive their water supplies from groundwater and pollution is presently negligible.

(4) The Institute of Geological Sciences in England is surveying all landfills in the country to assess problems of potential pollution. The hydrogeologic character of each site is considered, and based on subsurface conditions, each is subjectively classified into one of three categories: no risk, some risk, and serious risk. Forms on 1000 landfills have been received and 800 have been classified to date. So far only 3 percent have been classified as serious risks.

(5) A question was raised as to whether the licensing of a landfill site by the government provides legal protection against subsequent possible pollution.

(6) A point repeatedly raised and debated was that because groundwater pollution depends upon local hydrogeologic conditions, only a site-by-site investigation can insure pollution control. Others stated that general guidelines are needed now and could and should be established by government agencies to assist and protect the public. Contrasting conditions in chalk, alluvium, and sandstone were cited. The need for more research was generally accepted but not as an alternative to immediate government actions.

(7) No one at the conference could suggest any source of information on microbial degradation of cyanide under anaerobic conditions.

(8) Major concern for pollution in England centers in the heavily fissured chalk aquifers. Groundwater movements of 11 miles in 3 days were reported.

(9) The K/Na ratio is a useful indicator of pollution from landfills in comparison with natural groundwater. Bacterial pollution from landfills is rarely found.

(10) Two examples of E. coli groundwater pollution, both occurring at the same water supply pumping station, were presented. One resulted from a nearby leaky sewer, and the other from a nearby open construction trench. In both instances the pollution ended rapidly after repairs were made -- flow was through fissured sandstone.

(11) Chlorination of water supplies should never be done inside wells as this masks detection of actual groundwater pollution.

(12) An informal report by a professor at the University of Bristol described numerous field measurements of groundwater flow in fissured limestone. Spores and fluorescent dyes were used as tracers. Flow rates ranged from 3.45 to 7.36 km/day. Another person mentioned studies elsewhere giving rates of 2 km/day.

(13) Sulfide in inactive wells was reported due to sulfate reducing bacteria and causing pitting of steel casings. Bacteria live under nodules on the casings and cannot be removed by chlorination. They live in anaerobic conditions. Bacteria can be controlled by raising the pH to 10 and effects can be minimized by using nonferrous materials in wells.

(14) The safe overland transport of potential pollutants was discussed together with the need for safety precautions, for informing government agencies of transport plans, for notification of accidents, and for training of police and firemen for such emergencies. Trucks carrying hazardous substances must be properly labeled. Some chemical companies maintain their own emergency staffs.

(15) Manure and oil-contaminated soil can be disposed of by spreading them in thin layers on the ground surface where they are oxidized within a few months.

(16) Pollution analysis of dune sand in Netherlands after 17 years of recharging river water through it showed that organic matter is concentrated near the surface with most of it in the first 10 cm and essentially pure sand at a depth of 1 m. There were no long term residual effects at depth and no oil accumulation in the sand.

(17) Polluted groundwater can pose health problems in mines.

(18) Prevention is better (that is, easier and more effective) than treatment of groundwater pollution.

(19) Monitor wells around a landfill can be used for remedial pumping, if needed.

(20) The paper by Dr. Exler of Munich, West Germany, was the most detailed and best documented field study. Here pollution from a large landfill is monitored by 70 observation wells which are logged every two weeks for electrical conductivity and temperature. The pollution tail has moved more than 3000 m downstream from the landfill.

(21) Oil spills in sandy aquifers move down to the capillary zone of the water table and then spread laterally. Pumping of groundwater affected by oil spills does not eliminate the oil but does limit the spread of oil. Oil spills in fissured aquifers move freely but ones in alluvial aquifers do remain in a localized area. There are no experiences from Switzerland involving fissured aquifers.

(22) There are 50 to 60 petroleum and other pipelines between Rotterdam and Antwerp. Many have small constant leaks of a few liters per hour. It has been proposed to have each pipe protected by another surrounding pipe for cathodic protection and for drainage of

leaks. Another proposal is to place pipes in PVC drainage channels to catch any leaks.

(23) Problems of bursting oil pipelines are emergencies involving human life and must be handled by the police and firemen. Some oil companies have established emergency procedures for pipeline breaks. In Western Europe there is a special organization known as STICHTING CONCAWE, established by the oil companies, for study of methods to conserve clean air and water. In Switzerland oil tanks are not permitted in watershed areas.

(24) The director of the Water Research Association stated that a basic objective of groundwater pollution control and monitoring should be to keep clean water clean.

(25) In England a new Poisonous Waste Act went into effect on August 3, 1972. The law makes it an offense to deposit on land (including land covered by water) wastes of a poisonous, noxious or polluting nature which could cause an environmental hazard. Such a hazard is defined to include circumstances where pollution or contamination of water -- either surface or underground -- is threatened (it is not necessary to show that actual pollution has occurred). A three day notice must be given to the local river authority before transporting or depositing wastes. The government authority does not approve notices but does have the opportunity to object. The law has greatly increased local government work loads; one authority receives over 200 notices per week. About one-third of the notices are unsatisfactory because of incomplete data. The act contains a list of materials that are considered toxic. Although the act is imperfect, it is providing for the first time information on what wastes are going where, and it is encouraging industries to reduce their volumes of waste materials.

(26) There was considerable discussion on movement of groundwater in chalk aquifers. Tritium tracer studies showed vertical percolation rates of the order of 1 m/yr, yet field reports describe movement of water in fissured chalk of several km/day. Clearly the degree of local fissuring is a key factor.

(27) Waste disposal wells have recently been started in Netherlands. There is no legislation yet on the subject.

(28) It was suggested that disposal wells terminating in fresh water aquifers should be distinguished from those in salt water aquifers.

(29) There was discussion of the pros and cons of deep well disposal versus treatment or processing of harmful or toxic wastes.

(30) One closing comment was an estimate that the conference had spent 30 percent of its time on scientific aspects of groundwater pollution, 30 percent on prevention of pollution, 30 percent on reports of pollution occurrences, and 10 percent on cures for pollution.

(31) Another closing comment was that there was need for guidelines describing the symptoms of groundwater pollution, the actions required for controlling and limiting pollution, and the monitoring of pollution. Also, specifications were needed for the circumstances causing groundwater pollution and the methods for its diagnosis.

(32) A facetious closing comment mentioned that a fire brigade to control groundwater pollution needed:

(a) a bucket and spade for pollution near ground level,
(b) a mop and bail for pollution within a well, and
(c) a scavenger well for pollution within an aquifer.

SECTION 5

INFORMATION FROM EUROPEAN COUNTRIES

Between the sessions at the conference the author met and talked to many men, mostly government representatives, from several European countries. Almost all of the men offered assistance in securing information regarding government practices and policies in regard to groundwater pollution. Such information could be obtained by correspondence or by follow-up visits to specific countries. Those countries which can be expected to contribute the most information are England, The Netherlands, France, West Germany, and Switzerland.

Much information on governmental procedures in various European countries was presented in the conference papers and, therefore, will not be repeated here. However, from conversations at the conference and subsequent correspondence, additional facts from four countries were obtained. These are described in the following sub-sections.

DENMARK

An estimated 500,000 individual subsurface oil tanks exist in Denmark. Thousands of these leak, often from cathodic corrosion, but only 11 cases have been fully documented. There are government regulations pertaining to the installation of these tanks on farms.

SWITZERLAND

Oil pollution is the major problem in Switzerland. About 90 percent of the houses are heated by oil stored in subsurface tanks. The population is concentrated in the alluvial valleys. Oil spills and leaks tend to remain in the capillary zone within a limited circle. Concentrations of oil in groundwater are small, usually less than 1 mg/l, but tastes and odors may be adverse effects. Also, the effect

of bacteria in the subsurface for oxidizing organic pollutants is not known. There is no general summary of the Swiss groundwater pollution situation because records are located in the 23 cantons; however, some information can be obtained from Bern. Oil spills do not go away but tend to form a cumulative collection which can gradually affect most of an alluvial aquifer. In localized oil spills it is common practice to remove the oil-contaminated soil. This must be done carefully, however, by excavating in uniform horizontal layers. If, in haste, a large deep hole is dug, oil drains to the bottom of the hole and contaminates deeper layers of the aquifer before it can be removed.

THE NETHERLANDS

At the conference the author had the opportunity to meet Dr. H. G. van Waegeningh, a geohydrologist with the Netherlands Government Institute for Water Supply in The Hague. As a result of conversations on the prevention and control of groundwater pollution, Dr. van Waegeningh promised to send more detailed information. His letter, reproduced below with only minor editing, is an excellent unofficial statement of the Dutch situation and viewpoint.

24th October, 1972

Dear Prof. Todd,

As I promised you a few weeks ago at Reading, I will tell you something of the protection of the groundwater quality in the Netherlands (technical and legal aspects), and I separately send you a copy of German directions and a German law.

Groundwater-management has two aspects: the quantitative and the qualitative management of groundwater resources. Both aspects of course are narrowly interrelated; a very clear example is the encroachment of salt water into a fresh water aquifer caused by over-pumping. Another example is the artificial recharge of groundwater by infiltration of more or less polluted riverwater. Mostly these interrelations are of importance in special cases (but then often at a large scale); in the following I will not digress on them.

As to the quantitative aspects it has to be remarked that in general the groundwater in the Netherlands is directly replenished by rainfall; the effective rainfall (rainfall minus evapotranspiration) amounts to about 0.25 m/year. Over the country's surface of 35,000 km^2 this produces an average yearly replenishment of the groundwater (renewal of the resource) of 8.75×10^9 m^3. Most of the groundwater drains to ditches, brooks and rivers, while at the moment about 1×10^9 m^3 is pumped for water supply. This groundwater recovery is a very complicated affair, because it has many connections with the interests of agri- and horticulture, forestry, surface water management, conservation of nature and landscape, and salt water encroachment. To get the right insight into all the interrelations, we try to work with models for optimization. These models have to give us the directions for where, how, and how much water we may withdraw from the underground. Nowadays we estimate that a withdrawal of 1.5 to 2×10^9 m^3/year is possible. However the total water demand in the Netherlands in the near future is estimated at 4.5×10^9 m^3/year; consequently, a large supply from the surface water resources will be needed. The only important rivers we can use for that purpose, are very badly polluted rivers, the Rhine with a high basal flow and the rain-fed river Meuse.

The management of ground and surface water up till now is practiced by different ministries and is subject to different laws. As to the surface water we can say that in the Netherlands both the quantitative and the qualitative management is legally settled. As I am not a surface water specialist, I will not write on that subject, but restrict myself to groundwater.

There is not yet a national law on the quantitative aspects of the groundwater. Only the public water works undertakings have to ask permission for a withdrawal of groundwater to the Minister of Public Health and of the Environment; the Minister is advised by a committee of specialists in the fields of hydrology, agriculture, forestry, nature conservation, and water management. In many of our provinces, however, industry is still free to pump groundwater and so they do in really big quantities. Sometimes the municipal authorities submit the industry to some law that was not made for that purpose at all. Awaiting a national law, the provinces have prepared provincial regulations. The national law will only give general outlines, which will have to be detailed by

the provincial boards. Advice on the admissibility of a withdrawal by a multidisciplinary committee to the board will be possible.

Also for the qualitative aspects there is not yet a national law available; we still have to work with laws that were not made for that purpose and with some provincial regulations on soil- and groundwater pollution. At this moment a law on waste disposal is in preparation, which has been given priority above, the soil- and groundwater polution law. With the regulations we have nowadays, we are able to protect more or less the groundwater quality in the vicinity of the well-fields for public water supply; this may result in the fact that the groundwater may be polluted anywhere outside the protected areas around the well fields, i.e. the greater part of our country. I think that therefore we will meet difficulties when starting the exploitation of new pumping stations.

With regard to the protection of the groundwater quality, we distinguish pollution of a bacteriological nature and of a chemical nature. The bacteriological protection area around a well field has to be so big that the pumped water has a retention time in the underground of at least two months. After that time the possibly present bacteria are mineralised and do not threaten the public health anymore; in our country the distributed water is not or only slightly chlorinated. Of course the groundwater may be enriched in mineral content by the decay products of the bacteria. Little is known of the behaviour of viruses in the underground, but the first results of research indicate that they do not survive a two-month stay in the underground. Within this protection area certain directions are in force for the use of the land and for doings on which I will come back later. Anticipating also a later paragraph, this area contains the areas I and II, respectively — the well field proper and a 2-month stay area around the first one.

The chemical protection area has to safeguard the water from "chemical" pollution, especially by inorganic and organic-chemical admixtures; these substances are hardly or not degraded to harmless parts in the underground. Adsorption to soil particles will take place to a certain degree, while also dilution and dispersion will occur. Of all these processes in the underground, very little is known. As a "standard" we assume that after transport over a distance of two kilometers, the pollutants are

diluted so strongly that they do not give difficulties in the purification and the reliability of the pumped water. So in principle the chemical protection area has to cover an area extending two kilometers from the well field in an upstream direction and smaller distances in other directions. This area is the same as the areas III a and b, which will be discussed later. In this area the use of the land surface and the works to be carried out are restricted.

The size of both types of protection areas is highly dependent on the geology and hydrology of the region. Layers of clay or loam above the aquifer mostly are a good safeguard against pollution from above; sometimes practically no protection area is necessary. On the other hand a very great area may be necessary, e.g. in the case of phreatic water in fissured or karstic rocks. Other important factors are the transmissibility of the aquifer, the flow pattern of the groundwater, the depth of the well-screen, etc.

In the Netherlands we mostly have unconsolidated, sandy aquifers; the bacteriological protection areas vary from 15 to 300 meters. The chemical zones, 1/2 to 2 kilometers. In this densely populated and highly industrialised country, we do not meet big problems in the designation of the bacteriological protection areas. Because of the big size of the present chemical protection areas, research on the behaviour of chemical pollutants in the underground has to be done, so that these areas may be reduced to a scientifically more justified size, in order to avoid exaggerated occupation of the limited space available.

For the different protection areas several directions are to be applied on the use of the terrains involved and the works there in. For these rules I always refer to a German standard on that subject, the "Richtlinien fur Trinkwasserschutzgebiete" (directions for the protection of groundwater catchment areas), published by the "Deutsche Verein von Gas- und Wasserfachmannern" (D. V. G. W. – German Gas and Water Works Association; address P. B. 970169, Frankfurt (Main) Germany). A copy of them is sent separately to you. These directions agree with the existing ideas of protection in the Netherlands and are handily tabulated in these "Richtlinien". One of the prominent authors is Prof. Dr. F. Noring, Director of the Geological Survey of the State of Hessen (Hessisches Landesamt fur Bodenforschung), Leberberg 9, 62- Wiesbaden, Germany.

After a simple introduction of the problems and the factors involved, three types of protection areas are distinguished:

a. Area I — the actual well-field.
b. Area II — the bacteriological protection area.
c. Area III — the chemical protection area.

For these areas the directions are given. Formerly in the Netherlands we distinguished also three areas, but nowadays we only distinguish the bacteriological area — area I + II and the chemical area — area III. The starting point for this is that the actual well field has to be the property of the water company so that the latter can control the land use and works in that zone. The German directions were published in 1961; because of more knowledge on the subject and experiences with the directions, a new version will be published in short time. After the protection of groundwater, the D.V.G.W. also published directions on the protection of storage reservoirs for water supply and of mineral water wells; these I do not have, so I cannot send you a copy.

According to the German law on Water Management (Wasserhaushaltsgesetz, 1967) the designation of protection areas is legalised. That law only gives the general outlines; the German states have to fill up this framework.

Recently in the State of Rhenania-Westphalia a detailed legislation came into operation; a copy of that law also has been sent separately to you. In this law all the above mentioned directions of the "Richtlinien" are included; moreover, the whole procedure for the designation of the areas is given, together with a regulation for a settlement of damage to landowners.

With this letter and the copies sent I hope to have given you an short impression of the ideas on groundwater protection and the legislation in the Netherlands and Germany. Of course I still could write you many more "theoretical" pages on the subject, but perhaps still more pages on the practical side of the problem. In practice we often have to look for a compromise, while in many cases it will be possible to take measures in order to prevent soil- or groundwater pollution by certain works (e.g. pipelines, highways, parking places, sewerage, oil drilling, etc.).

Yours very truly,

/s/ Drs. H.G. van Waegeningh

WEST GERMANY

The concept of protection zones around water supply installations to prevent groundwater pollution originated in West Germany. As mentioned in the above letter from Dr. van Waegeningh, the authoritative reference on protection zones is the German document Richtlinien fur Trinkwasserschutzgebiete. Because of the value of this reference, an English language translation has been prepared and is reproduced below.

Regulations for Protective Areas for Drinking Water
Part I - Protective Areas for Groundwater
by
Deutscher Verein von Gas- und Wasserfachmannern e.V.
Frankfurt (Main), Rheinganallee 90-98

Table of Contents

1. General
2. Significance of Protective Areas for Groundwater
3. Threats to Groundwater by Pollution and Other Contamination
3.1. Pollution and Other Contamination
3.2. Danger Centers
3.3. Routes from Danger Centers to Groundwater
3.4. Purifying Effect of the Underground
3.5. Resistant Materials
4. Instructions for the Division and Measurement of Protective Areas
4.1. General
4.2. Character of the Underground as a Basis for the Arrangement and Measurement of Protective Areas
4.3 Organization of Protective Areas
5. Type and Extert of Protective Measures and Protective Zones
5.1. General
5.2. Area of Collection (Zone I)
5.3. Lesser Protective Zone (Zone II)
5.4. Greater Protective Zone (Zone III)
6. Plant's Own Control of the Protective Area

1. General

1.1. Groundwater which is naturally free of qualities threatening health and which is according to its origin and condition

of pleasant taste deserves to be preferred to all other drinking water.

1.2. The groundwater has to be protected in the interest of national health from detrimental influences.

1.3. The protection of the drinking water is of special importance in comparison with other competing interests.

2. Significance of Protective Areas for Groundwater

2.1. Groundwater is through its use and the utilization of the available underground formations exposed to many dangers. These dangers can be diminished or excluded to a great extent through the installation of protective areas.

2.2. The protection of the groundwater, because of a variety of possible dangers, becomes important not only in the vicinity of the plants for groundwater development but also in the entire groundwater basin as well.

3. Threats to Groundwater by Pollution and Other Contamination

3.1. Pollution and other contamination of groundwater

3.1.1. Groundwater can be polluted in particular by:

a) Viruses, bacteria, and other organisms;
b) Organic and inorganic materials, for example pesticides, petroleum, mineral oil and in particular fuel oil, gas, tar, carbolic acid, detergents, turbid agents and dyes, scenting materials and flavorings, arsenic, lead, chromium and cyanide compounds, fertilizer;
c) Radioactive materials.

3.1.2. Groundwater can also be contaminated or become unsuited for drinking through other agents like chlorides, sulfates, nitrates, phosphates, calcium and magnesium compounds, iron and manganese compounds (oversalting, hardening, etc.).

The same can happen through physical changes, for instance through temperature increases or changes in surface tension.

3.2. Danger Centers

Pollution or other contamination of the groundwater can originate especially through depositing harmful materials into the substratum or into the water as well as through the placing of such materials on the surface of the ground In this respect danger centers can be among other things the following (the order of enumeration does not mean to rank through evaluation):

a) Plants which turn out harmful waste products or back water (also cooling water);
b) Production, storage, manufacturing, and transport of harmful materials;
c) Settlements (built-up areas, scattered settlements, separate farms);
d) Drainage and infiltration of wastewater;
e) Airports, dumps, military buildings, and training camps;
f) Extraction, production, transport, storage, cultivation and other utilization of radioactive materials;
g) Gravel, sand, peat,and clay pits; drillings; quarries, as well as other exposures in the earth; exposure of the groundwater surface;
h) Removal and damage to the soil and covering layers;
i) Effects of mining;
k) Underground blasting;
l) Camping, swimming, and athletic fields;
m) Washing of motor vehicles;
n) Boat and ship traffic;
o) Vehicle traffic (including those on tracks);
p) Cemeteries;
q) Fertilizing and pasture land;
r) Nurseries, small gardens;
s) Parking lots;
t) Pedestrian traffic;
u) Surface water;

v) Flooding, thaws, heavy rains, and artificial irrigation;
w) Open shafts and tunnels as well as tunnels, canals, shafts, wells, filled pits and bomb craters, etc., that have beer abandoned or forgotten and are difficult to recognize on the surface.

3.3. Routes from Danger Centers to Groundwater

3.3.1. The contaminating and harmful materials or influences can reach and be transferred into the groundwater and into aquifers in various ways, for instance by infiltration, inflow, leaching, and drainage.

3.3.2. For stream inflow, artificial groundwater recharge, and limestone areas, etc. (see paragraph 3.4.4.), the danger centers can be effective over longer distances as well.

3.4. Purifying Effect of the Underground

Pollution and other contamination of groundwater can be diminished or removed through the purifying effect of the underground.

3.4.1. The purifying effect of the underground is based as much on the purifying filtering effect of the layers as on the length of time the water remains. For the most part the following processes work together:

a) Physical processes, e.g. retention in the pores, dilution;
b) Physical-chemical processes, e.g. adsorption on the soil particles;
c) Chemical processes, e. g. oxidation, exchange of ions;
d) Biological processes, e. g. absorption through roots of plants, bacterial decomposition. Besides the actual purifying capacity of the underground, the dying of bacteria and microorganisms, which as a rule begins under normal subsurface conditions (also in water in cracks) after approximately 50 days, plays a significant role in the purification as well.

3.4.2. The course and success of these processes depend especially on the following facts, which vary according to locality and are probably correlated with one another:

a) Type, degree, amount of material, duration, frequency of the pollution or other contamination;
b) Extent, nature, and agricultural condition of the layers above the groundwater surface;
c) Extent and nature of the groundwater aquifers;
d) Naturally and artificially produced depth to and fluctuation of the groundwater surface;
e) Length of travel and time it takes for a water particle to be removed from the soil after it has entered the subsurface (the more water pumped, the more the level of groundwater in the aquifer decreases and the marginal speed increases, accordingly the length of time the water stays is shortened);
f) Climate and season.

3.4.3. The essential part of the purification process takes place in that layer of the soil containing life, further purification takes place in the lower layers mainly through physical and chemical processes. However, a precondition for a persistant and sufficient purifying effect is that the effect is not constantly decreased or even neutralized through overloading.

In regard to stream inflow water the purifying effect depends such as the case may be as much on the nature of the contact zone between the waters above ground and the substratum as it does on the kind of neighboring layers. Temporary draining of the soil, shipping traffic, fisheries, swimming, etc., as well as floods and drifting of ice can destroy the filtering and biologically effective contact zone. The loading with wastewaters of surface waters has the utmost influence here. The temperature balance and the purifying capacity of the soil layers exert an influence on the flow up to the point where the water reaches the zone of saturation. This effect, however, is decreased by flood waters, if a significant rise in water level or a flood occurs.

The uppermost layer in an artifical recharge area, that is the contact zone of the infiltrating ditches or basins, carries

out the main part of purification of the surface water used. The lower layers of the soil bring about the last improvement in quality and balance of temperature; this is also true for plants used for underground recharge, since the main part of the purification of the surface water is the task of a preceding artificial treatment process.

3.4.4. Groundwater which flows in wide fissures and cracks, in limestone areas, through river boulders, and in coarse gravels without the essential fine particles is not sufficiently purified in most cases, even if the distance it flows is many kilometers long.

3.5. Resistant Materials

Materials like oil, fuel, tar materials (especially carbonic acids), detergents, metal poisons, caustic lye, pulp solutions, non-ionic radioactive substances, etc., do not, as a rule, lose their harmful effects on the groundwater in spite of long flow distances and long durations in the underground.

4. Instructions for the Division and Measurement of Protective Areas

4.1. General

4.1.1. The installation of protective areas cannot be carried out schematically, since almost each case is different. Because of this, preliminary studies are necessary for comprehensive evaluation.

A knowledge of the following conditions is especially important:

a) Kind and extension, condition, and effect produced by the aquifer;
b) Amounts pumped from the aquifer (also future amounts);
c) Results from chemical investigations;
d) Geological structure;
e) Hydrological conditions;
f) Groundwater collection area;

g) Form of the area;
h) Type and structure of the soil;
i) Possibilities of groundwater dangers by pollution or other inflowing groundwaters;
k) Existing and planned utilization of the area, e.g. cultivation, soil utilization, highways;
l) National parks and preserves;
m) Mining rights, plants, and projects.

In the case of stream inflow and of artificial groundwater recharge, the water above ground has to be carefully studied.

4.1.2. For the division and protection of the protective areas investigations made by specialists for each individual case are necessary, e.g. considering water conservation, geological, hydrological, hygenic, and chemical viewpoints.

New circumstances and scientific discoveries also have to be taken into account.

4.2. Character of the Underground as a Basis for the Arrangement and Measurement of Protective Areas

4.2.1. The character of the underground is of deciding importance for the arrangement and measurement of protective areas. In addition to this the kind and extent of the well field plays an important role.

4.2.2. According to the purifying effect (capacity of purification of the layers and duration of the water contact) of the upper layers as well as of the groundwater zone, one differentiates between

a favorable condition of the underground,
an average condition of the undergrounds, and
an unfavorable condition of the underground.

4.2.2.1. Favorable condition of the underground

The aquifer is covered by permeable and purifying, by heavy, or by non-permeable upper layers of soil.

Permeable and purifying upper layers must have a continuous surface thickness of

(a) 2.5 meters in clayey sand, fine sand, and other types of soils with a permeability that is not greater than that of fine sand,

(b) 4.0 meters in average sand, coarse sand, graveley sand, and other types of soils with a permeability not greater than that of average sand.

Semi-permeable or non-permeable covering layers are those which consist, for example, of clay, loam, sandy loam and other types of soils with a permeability that corresponds to that of clay or silt and have a thickness of at least one meter. These layers must be protected against pervading dry cracks by a sufficient depth to their base, by a covering with non-cohesive types of soils, or by a continuous increase in moisture from below.

4.2.2.2. Average condition of underground

Sometimes there are no cover layers of the type described in paragraph 4.2.2.1., are missing in part or completely, or their thickness is less than called for in paragraph 4.2.2.1. The aquifer receives groundwater that does not travel slowly enough and lacks adequate filtering so that it does not have sufficient purification.

4.2.2.3. Unfavorable conditions underground

The covering layers described in paragraph 4.2.2.1. are partially or completely lacking, or their thickness is less than called for in paragraph 4.2.2.1. The aquifer is so constructed that the groundwater undergoes insufficient purification due to the short amount of time the water remains and due to lack of any significant filtration.

4.3. Organization of Protective Areas

In general a protective area is arranged as follows:

(a) Area of Collection (Zone I)
(b) Lesser Protective Zone (Zone II), and
(c) Greater Protective Zone (Zone III).

4.3.1. The Area of Collection (Zone I) is the immediate environment of the well field. It must be protected from any pollution and other contamination.

4.3.2. The Lesser Protective Zone (Zone II), as a rule, is adjacent to the Area of Collection. It must be protected from pollution and other contaminants, which under given circumstances will not be completely removed through the purifying effect of the underground until reaching the well field.

4.3.3. The Greater Protective Zone (Zone III), as a rule, joins the Lesser Protective Zone and must be protected from pollution and other contaminants, the results of which under given circumstances will not be or almost not be removed through the purifying effect of the substratum. Its outer limit must by all means be identical with that of the area of collection of the groundwater. It can be of use to subdivide the Greater Protective Zone into Greater Protective Zone A (Zone III A) and Greater Protective Zone B (Zone III B).

4.3.4. Protective zones do not have to extend beyond a point where there is maximum withdrawal of water and a minimum inflow of groundwater.

5. Type and Extent of Protective Measures and Protective Zones.

5.1. General

All protective measures which are needed for the Greater Protective Zone are fundamentally necessary for the Lesser Protective Zone, also measures for the Lesser Protective Zone apply to the Area of Collection (see Appendix).

5.2. Area of Collection (Zone I)

The Area of Collection should guarantee the protection of the well field from direct pollution and other contamination. In this zone any possibility of pollution and contamination must be checked.

5.2.1. All dangerous uses in Zones II and III are especially harmful in this zone and generally fatal.

5.2.2. It is desirable that these zones be under the control of water supply management. They should be covered with a connected grasslayer. All damages to the layer containing life and to the covering layers must be prevented. The covering layers can be strengthened by adding purifying or waterproof material. These areas should be protected against erosion and floods. The requirements for the groundwater collecting area do not permit blasts, even if they are intended for geophysical purposes. The same is true for the chemical control of insects and weeds.

5.2.3. It is necessary to protect the well field area in a suitable way against trespassers, for instance with fences.

All actions necessary for the functioning of the waterworks have to be carried out in a way that they do not have any harmful effect on the groundwater. Installations necessary for the functioning of the works, e.g. storage of material, especially of fuel, lubrication oil, heating material for machine works, and production of energy as well as of chemicals for the treatment of the water must be provided with effective devices for the protection of the groundwater.

5.2.4. When pumping artificially recharged groundwater, the area where the groundwater is recharged should also be under the control of the water supply plant and should be protected according to the requirements of the collecting area.

5.2.5. Extent of the collecting area: all sides from the point of the well field and in the direction of inflowing groundwater should be, in general, 10 meters to 50 meters away (in special cases less but extending to such a point that animal fertilizer can be admitted in Zone II).

5.3. Lesser Protective Zone (Zone II)

The Lesser Protective Zone (Zone II) should guarantee protection against bacteriological pollution which originates through man's own actions.

5.3.1. In addition to the uses described as harmful in Zone III, one has to consider dangerous and generally fatal those uses which are connected either with the constant presence of man or the destruction of the surface layer containing life and the upper layers. Such uses are (the order of enumeration does not mean rank through evaluation):

a) Construction, especially apartment houses, stables, silage clamps, and industry;
b) Gravel, sand, peat- and claypits, mining, sunken roads, and quarries, through which the layer containing life would be damaged and the upper layers diminished, especially when the groundwater is constantly or at times exposed at high levels or the poorly purifying layer is exposed;
c) Transport of liquids harmful to groundwater, e.g. fuel oil, fuel, and solvents;
d) Dumping of rubbish and waste products;
e) Animal fertilizer, as far as the fertilizer is not spread immediately after transportation -- otherwise there is the danger that it would be washed into the collecting area;
f) Incompetent use of pesticides and artificial fertilizer;
g) Fertilizing with ammonia water from gasworks, etc.;
h) Agricultural or small garden irrigation with impure water;
i) Drainage of sewage from ditches containing water from areas outside Zone II.
k) Ensilage;
l) Mining, if it leads to damage of good cover layers or to basin shaped ground and to open water collection;
m) Washing of motor vehicles;
n) Camping, picnicking, and swimming;
o) Parking lots;
p) Athletic fields;
q) Burying of animals;
r) Paved roads and streets for motor vehicles, if the water collecting on them is not drained from them by means of water-tight road ditches or canals from the Lesser Protective Zone; use of tar for road construction;
s) Expansion of highway systems;
t) Small gardens and nurseries.

5.3.2. The following measures should be taken to diminish existing dangers until they can be finally eliminated:

a) Providing existing buildings with water-tight sewer connections;
b) Repairing sewers and old wells;
c) Protecting the area against floods, as far as necessary;
d) In the case of stream channels filled with wastewater, protecting against losses by leaching or transfer from this zone;
e) Filling of cavities and excavations with satisfactory material;
f) Fencing of excavations with exposed groundwater levels;
g) Removing of existing harmful residues;
h) Detouring traffic.

5.3.3. Extent of Zone II: in the case of a circular well field in the direction of the approaching groundwater up to a line from which the underground water needs approximately 50 days until it reaches the wells, or at least 50 meters.

Zone II can be eliminated if thick waterproof materials are used which provide cover from the 50-day-line up to the well field with impermeable layers of sufficient extent.

5.4. Greater Protective Zone (Zone III)

The Greater Protective Zone (Zone III) must guarantee protection against extensive chemical and radioactive pollution and other contamination of the groundwater.

5.4.1. It is useful to divide the collecting area into a Zone IIIA about 2 kilometers from the well field and a Zone IIIB approximately 2 kilometers to the borderline of the collection area, if the collection area is greater than two kilometers. (In limestone areas the 50-day-line, which defines Zone II, can in certain parts, extend beyond two kilometers from the well field and up to the borderline of the collection area). If Zone III is not divided the following statements about Zone IIIA are applicable.

5.4.2. Beyond those harmful measures listed for Zone III B, the following are detrimental for Zone III A (the order of enumeration does not serve to rank through evaluation):

a) Drainage of surface runoff and wastewaters;
b) Built-up settlements and industry without drainage;
c) Containers for fuel oil and fuels of more than ten cubic meters capacity, and in the case of those lacking additional protective measures, up to ten cubic meters capacity;
d) Gas stations and fuel tanks;
e) Airports, dumps, military buildings, and training camps;
g) Pipelines for crude oil;
h) Dumps for refuse and dumps with material which can leach;
i) Purification plants;
k) Emptying of vehicles for faeces transport;
l) Septic tanks;
m) Recharge of cooling water in large quantities;
n) Large excavations without sufficient protection;
o) New cemeteries.

5.4.3. In Zone III B the following is to be considered dangerous:

a) Recharge of wastewaters and radioactive materials;
b) Dumping of materials with easily leached chemicals, e.g. dumps with residues of potash works and dumps of chemical industry;
c) Dumping of oil, tar, carbolic acids, residues of oil drillings, poisons and pesticides in open and not sufficiently protected pits;
d) Fuel- and oil-pipelines;
e) Plants with harmful wastewaters, if the wastewaters are not completely and securely drained from the area or sufficiently treated.

5.4.4. Plants with dangerous wastewaters need to be considered:

Battery manufacturers
Ammonia plants
Tanneries and other plants which use caustic liquids
Bleaching plants
Chemical plants

Oil refineries, large oil tank installations
Dye works
Photochemical works
Gasworks, coking plants, plants for the generation of gas
Tanneries
Rubber plants
Hydroelectric plants
Isotope plants
Potash plants, salt works
Synthetic fiber works
Leather works, dye houses for leather
Mineral dye works
Mineral oil works
Sulfuric acid works
Distilleries
Alkali works
Explosives plants
Aniline dye works
Textile works (except drying plants), including synthetics
Galvanization plants
Detergent plants
Laundries
Tin works
Cellulose works
Sugar factories
and other plants which produce one of the named items as a secondary industry.

6. Plant's Own Control of the Protective Area

6.1. The plant's own control of the protective area serves to localize as early as possible influences and changes which are of importance for water conditions.

6.2. The water supply management should observe the possibilities for the protection of the groundwater from harmful influences, and should provide for the observance of the current protective regulations.

6.3. It has to make efforts in the remaining protective areas to establish controls which are necessary for the observance of the current protective regulations. Furthermore, these

observations should encompass important changes in the protective areas and in the collecting area, in cases of acquisition of induced streamflow water or artificially recharged goundwater, as well as surface water.

6.4. The water supply management should within its groundwater study observe also the chemical quality in the groundwater supply lines and, if present, in other groundwater openings, especially if dangers, e.g. from harmful materials seem imminent. It is recommended that careful current records be kept of all observations.

Appendix

Section Number	Dangerous Processes*	In Zone			
		I	II	III A	III B
5.4.3.a	Recharge of wastewaters and radioactive materials	+	+	+	+
b	Dumping of materials containing easily leached chemicals, e.g. residues of potash works, chemical industrial wastes	+	+	+	+
c	Dumping of oil, tar, carbolic acid, the remains of oil drillings, poisons, pesticides in open and carelessly covered ditches	+	+	+	+
d	Subterranean fuel and oil lines	+	+	+	+
	Industrial wastes, if the wastes are not completely and securely drained from the area or sufficiently treated	+	+	+	+

*Symbol + equals dangerous, and - equals not dangerous.

Section Number	Dangerous Processes*	In Zone			
		I	II	III A	III B
5.4.2.a	Drainage of surface runoff and wastewaters	+	+	+	–
b	Built-up settlements and industrial areas without drainage	+	+	+	–
c	Containers for fuel oil and fuel of more than 10 cubic meters capacity, and in the case that additional protective measures are lacking, those containers with a capacity of to 10 cubic meters	+	+	+	–
d	Gas stations, storage tanks	+	+	+	–
e	Airports, dumps, military areas, and training camps	+	+	+	–
f	Crude oil pipe lines	+	+	+	–
g	Plants for collecting radioactive materials and atomic energy	+	+	+	–
h	Rubbish dumps, residues with leachable substances	+	+	+	–
i	Purification plants	+	+	+	–
k	Dumping of vehicles for the transport of faeces	+	+	+	–
l	Septic tanks	+	+	+	–
m	Recharge of cooling water in large quantities	+	+	+	–
n	Large excavations without sufficient protection	+	+	+	–
o	New cemeteries	+	+	+	–
5.3.1.a	Construction - especially of all housing, stables, silos, and industry	+	+	–	–

Section Number	Dangerous Processes*	In Zone I	II	III A	III B
b	Gravel, sand, peat, and clay ditches, excavations, sunken roads, quarries through which that surface layer containing life is destroyed and through which the upper layers are diminished, especially if the groundwater is continually or at high levels is uncovered; or when a layer that purifies poorly is uncovered	+	+	–	–
c	Transport of liquids dangerous for the groundwater, e.g. fuel oil, fuels, solvents	+	+	–	–
d	Dumping of rubbish and waste materials	+	+	–	–
e	Animal fertilizers, in as much as the fertilizing material is not used immediately after transport, or when the danger of its surface solution into wells exists	+	+	–	–
f	Careless use of pesticides and artificial fertilizers	+	+	–	–
g	Fertilizing with ammonia from gas works and the like	+	+	–	–
h	Agricultural and small garden irrigation with impure water	+	+	–	–
i	Transport of wastewaters, also from ditches that contain water from areas outside Zone II	+	+	–	–
k	Ensilage	+	+	–	–

Section Number	Dangerous Processes*	In Zone I	II	III A	III B
l	Mining, if it leads to the damage of good upper layers or to cavities in the earth crust and open accumulation of water	+	+	–	–
m	Washing of motor vehicles	+	+	–	–
n	Camping, picnicking, swimming	+	+	–	–
o	Parking lots	+	+	–	–
p	Athletic fields	+	+	–	–
q	Burying of dead animals	+	+	–	–
r	Paved roads and streets for the passage of motor vehicles, if the water that falls on them is not drained away from Zone II by means of impermeable ditches or canals; use of tar for road construction	+	+	–	–
s	Expansion of highway systems	+	+	–	–
t	Small gardens and nurseries	+	+	–	–
5.2.2.	Damage to that surface layer containing life and to the upper layers	+	–	–	–
	Blasting	+	–	–	–
	Chemical control of insects and weeds	+	–	–	–
	Erosion, flooding	+	–	–	–
	Trespassing	+	–	–	–

SECTION 6

NOTES ON REFERENCE MATERIALS

The author spent the two days following the conference in the library of the Water Research Association at Medmenham. This provided an opportunity to examine numerous references from European sources on groundwater pollution. Notes were made from many references, however, no attempt was made to compile a complete list of references. The Association plans to publish as a part of its third conference volume, a comprehensive bibliography on groundwater pollution. This should serve as an excellent introduction to the European literature on the subject.

The European literature on groundwater pollution is extensive and pertinent to the problems being faced today in the United States. Indicative of the information available are the following three European publications noted at Medmenham:

(1) A Report to Queen Elizabeth II by the Royal Commission on Environmental Pollution (dated February 1972). Topics discussed include the confidentiality of information about industrial wastes, the impact of new products on the environment--particularly of wastes, and the disposal of toxic wastes on land. It was this last part of this report that led to the rapid passage by Parliament in July 1972 of the new Poisonous Waste Act.

(2) Industrial Wastes, A working party document embodying A Provisional Code of Practice for Disposal of Wastes, The Institution of Chemical Engineers, London (dated 1971). This is a detailed and carefully prepared document. Hazardous wastes, for example, are classified into groups: explosive, flammable, oxidizing, poisonous, infectious (including asbestos), corrosive, and radioactive.

(3) Proceedings of the Seminar on the Protection of Ground and Surface Waters Against Pollution by Crude Oil and Oil Products, organized by the Committee on Water Problems of the United Nations

Economic Commission for Europe and held in Geneva, December 1-5, 1969 (two volumes; dated 1970). The subject matter of the seminar was built around the following five topics:

(a) Survey of the situation with respect to ground and surface water pollution by crude oil and oil products in European countries.

(b) Advanced techniques and methods used for protection against failures of storage tanks, pipelines and means of transport for crude oil and oil products.

(c) Precautionary measures and warning systems applied in areas threatened by crude oil and oil products contamination.

(d) Advanced methods and equipment used for detecting and determining the degree of water contamination by crude oil and oil products.

(e) Advanced methods and measures undertaken for routine and emergency treatment in the case of surface water, ground water, waste water and soil contamination by crude oil and oil products.